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3555

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, November 21, 1902.

The 170th meeting was held this date at 12 W. 31st Street.

President Chas. F. Scott called the meeting to order at 8:15 and said that the Secretary had an announcement to make:

SECRETARY POPE:—At the meeting of the board of directors this afternoon, the following seventeen associates were elected:

Name.	Address.	Endorsors.
ANDERSON, COOPER, General Superintendent, Colorado Department, The Telluride Power Co., Telluride, Col.		P. N. Nunn. C. S. Ruffner. V. G. Converse.
APPLER, GRAFTON WALL, Student, Westinghouse M. Co., Pittsburg; residence, 422 Kelly Ave., Wilksburg Pa.		E. & C. F. Scott. M. Co., residence, E. M. Tingley. C. E. Skinner.
DARLINGTON, FREDERICK, Electrical Engineer, Great Barrington, Mass.		C. C. Chesney. D. C. Jackson. C. F. Scott.
DEAN, WILLIAM WARREN, Electrical Engineer, Kellogg S. & S. Co., Congress and Green Sts.; residence, 610 Jackson Boulevard, Chicago, Ill.		F. J. Dommerque. K. B. Miller. G. F. Durant.
EASTERBROOK, JOHN F., Electrical Engineer, Westinghouse E. & M. Co., Pittsburg, Pa.		C. F. Scott. J. S. Peck. C. E. Skinner.
FARMER, FRANK MALCOLM, Laboratorian U. S. Navy Department; residence, 580 Pacific Street, Brooklyn N. Y.		W. A. Anthony. H. J. Ryan. Julius Martin.
HIXSON, CLINTON JEROME, Engineer, Railway Department, Allgemeine Elektricitats-Gesellschaft, Acker-Strasse 71, Berlin, Germany.		William Maver, Jr. G. H. Gibson. J. H. Dressel.
MANSON, RAY HERBERT, Assistant Engineer, Kellogg S. & S. Co., Congress and Green Sts., Chicago, Ill.		F. J. Dommerque. J. C. Kelsey. B. S. Lanphear.
MARTIN, SIDNEY B. General Manager, Pittsburg Construction & Eng'g Co.; residence, 236 Dinwiddie St., Pittsburg, Pa.		C. F. Scott. J. S. Peck. E. D. Edmonston

NEWELL, FREDERICK WILLIAM, Assistant Electrical Engineer, The Otis Elevator Co., Yonkers, N. Y.	C. B. Manville. H. B. Smith. F. E. Herdman.
NEXSEN, RANDOLPH HALLIDAY, Electrical Engineer, Thresher Elec. Co., 120 Liberty St., New York City; residence, 302 St. James Pl., Brooklyn, N. Y.	A. F. Ganz. S. S. Edmands. O. P. Loomis.
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SEMPLE, BERT ERNEST, Meter Expert, General Electric Co.; residence, 408 East 43d St., Chicago, Ill.	James Lyman. T. P. Bailey. C. D. Haskins.
SESSIONS, FRANK LORD, Mechanical and Electrical Engineer, The Jeffrey Mfg. Co., Columbus, Ohio.	F. C. Caldwell. F. S. Hunting. C. S. Bradley.
SHELDON, SIDNEY ROBY, Professor of Electrical Engineering, University of Idaho, Moscow, Idaho.	D. C. Jackson. W. A. Layman. C. F. Burgess.
STEPHENS, ARTHUR HARLAN, Switchboard Attendant, Standard Elec. Co. of Cal., Electra, Cal.	George P. Low. J. D. Boyd. F. G. Baum.
WILLISTON, HARRY STODDARD, Assistant to Electrical Engineer, The Pennsylvania R. R., 864 Broad St. Station, Philadelphia, Pa.	C. F. Brackett. A. L. Rohrer. A. P. Jenks.

Total, 17.

And the following associates were transferred to membership.

Recommended by Board of Examiners, Friday, Oct. 24, 1902.

FRANCIS V. T. LEE, Engineer (Pacific Coast Department), Stanley Electric Mfg. Co., San Francisco, Cal.

HENRY NOEL POTTER, 510 W. 23d St. New York City.

PRESIDENT SCOTT:—Another action taken at the meeting of the board of directors this afternoon is one in which you may be interested, as showing in general the progress of the INSTITUTE, and one of the effects of the active year which we had under President Steinmetz. The volume of our papers and discussions has so increased that it has become necessary to issue our bound TRANSACTIONS in two volumes instead of one. The volume for 1901 contains some 920 pages of papers and discussions. During the first six months of 1902, which includes the Annual Convention, the number of pages reached 1200, and the indications are that for the year complete 1902 we shall have 1600 pages. We have therefore, decided to divide the year's TRANSACTIONS into two volumes. The volume covering the first six months of this year is to be issued at once.

VARIABLE SPEED MOTOR CONTROL.

INTRODUCTION BY PRESIDENT SCOTT.

The applications of electricity lead to the revolution of old methods, as well as to the evolution of new ones. Electrical apparatus not only replaces that which it supersedes and performs the work more efficiently, but it also broadens the field and leads to developments which were impossible by former methods. For example, the electric light does not simply replace indoor lamps and flickering street lights, but it has revolutionized the whole art and practice of illumination. The first railway motors were made to have a little greater power than the horses or mules which they replaced, but electric cars have increased in size and in speed, they have extended out from the city to the suburbs, they connect adjacent towns, and in a dozen years great systems have developed which have little in common with the horse cars. The electric crane has been the prime factor in modernizing the methods of manufacturing where heavy work is to be turned out. The electric distribution of power to the machines in a factory not only accomplishes more effectively the service which other systems of power distribution had accomplished, but it is capable of other things as well. Because volts and amperes are more easily measured than speed and torque, the power consumption of tools may now be definitely known. The electric motor affords an effective means of securing speed variation.

The revolution of old methods and the evolution of new ones are both taking place in the machine shop through the application of the electric motor to the driving of tools. Plenty of power effectively applied with a speed control which is wide and flexible, together with new kinds of cutting tools and heavier

machines in which to use them, make possible an increase of output which seems almost incredible.

In a sense, speed variation is a purely mechanical matter. The two factors which determine mechanical work are speed and torque. The relations between speed and torque may be varied in definite ratios by means of belts and pulleys or by gearing. There is, however, no general mechanical solution of the mechanical problem of speed variation, or variable speed control. There are devices by which either of several fixed ratios may be selected; for example, common cone pulleys which allow the shifting of a belt from one pair of pulleys to another having different diameters, or the counterpart of this, several sets of gears, either one of which may be selected at will. There are indeed a number of mechanical variable speed devices by which the speed ratio may be changed by very small increments. Many of these devices are quite successful over a certain limited range of speed variation or of power capacity. In general, those which are satisfactory over a fairly wide range are limited in the amount of power which they can transmit.

On the other hand, speed variation by the electric motor can be so successfully effected that it is quite common to think that the whole problem of speed control should properly be turned over to the electrical engineer. It is regarded as a matter of course that all mechanical means for accomplishing the result are to be discarded if possible and the difficulties which the mechanical engineer has failed to overcome in the purely mechanical problem of varying the ratio between speed and torque are to be imposed upon the electric motor.

It is reasonable to presume that the solution of a problem which has proved so difficult mechanically may involve electrical difficulties as well. Although electrical apparatus may be provided which will accomplish the desired purpose, yet this may be at the expense of added complication, additional apparatus, or increased cost. It is not proper, therefore, to decide *a priori* that because speed variation *can* be effected by an electric motor that the variable speed motor should *always* be used regardless of conditions; specific requirements and cost.

Electric motors for continuous current may be divided into two types, represented by the series motor in which the speed varies when the load changes, and the shunt motor which in general has a speed which is constant with different loads. The series motor is particularly adapted for railway service,

crane service and the like. The shunt or constant speed motor may operate at the same speed at all times, or the speed may be changed at the will of the operator, and the motor will then run at a desired speed independent of the load. The speed of the motor depends upon the number of turns in series in its armature, the strength of its field and the e.m.f. applied to its armature. In practice, speed changes are produced by one of these three methods, or by combinations of them. When the shunt motor is arranged to run at different speeds over a considerable range, it will usually be found that the generating plant and the supply circuits are of special type, or the controlling devices are of complicated form, or the motor is of greater weight and cost than it would be if it operated at one speed only. Therefore, a constant speed direct current shunt motor is to be preferred *per se* to a variable speed motor.

The alternating current induction motor like the shunt motor is inherently adapted for constant speed service. It may be used also for variable speed work with characteristics analogous to those obtained with the rheostatic control of a shunt motor with unvaried field. It may also be wound so that either of several numbers of poles may be used, thereby securing either of several definite speeds, which are sensibly constant with varying load. Just as a shunt motor may be operated at different speeds from generators giving different voltages, so the induction motor may be operated at different speeds from generators giving different frequencies. The single speed induction motor is, however, the type usually used.

In selecting the apparatus for a new plant it is proper to consider the problem as a whole, to take a general view before concentrating attention upon specific parts. What proportion of the power is to be supplied at constant speed? What proportion of the variable speed work cannot be served satisfactorily from a constant speed drive with variable pulley ratios or variable gear ratios? What proportion of the work which requires delicate speed adjustment falls within the range of simple and satisfactory mechanical speed changing devices? What advantage in lessened cost of equipment will be secured by group driving, by furnishing a single large motor for delivering the average power required by a number of machines instead of a large number of small motors each for delivering the maximum power of the machine to which it is connected? What advantage will there be under the particular surroundings of the installation in

reducing the complication and the amount of auxiliary apparatus and putting in motors of the simplest possible type? Taking the plant as a whole, what are the general advantages of one type of apparatus over another, and does the general balance sheet show that the advantages of individual speed control by means of the motors themselves are of sufficient moment to dictate the scheme and plan for the whole installation? The varying answers which will be given to these questions in different cases will necessitate different solutions to the problem of selecting the best system.

We are fortunate, this evening, in having presented to us several methods of speed control of continuous current motors. These methods are not theoretical and untried, but they have the prestige of being methods which are in actual commercial operation, and of having been selected by manufacturing companies as being well adapted for general service. Although speed control can be effected so admirably by the electric motor, it is fitting that we should not go too far and apply the variable speed motor indiscriminately. The various methods of control which we are to consider this evening must be taken as specific ways by which certain ends can be accomplished; and it must be recognized at the same time that there is the larger problem to be determined in connection with each proposed installation; viz., whether on the whole speed variation by the motor itself should be chosen.

THE OPERATION OF MACHINE SHOPS BY INDIVIDUAL ELECTRIC MOTORS.

BY R. T. E. LOZIER.

Data concerning the load factor and operation of machine shops, and a description of the advantages derived from the use of individual electric motors. Illustrated.

The individually-applied motor is now accepted as an established feature of every well equipped machine shop. The period of careful investigation, followed by that of cautious probation, is passed, and this type of power application has now been in practical service sufficiently long to provide data that can be studied with profit. These data enable one to make more accurate deductions than were possible in the past, and enable those unfamiliar with the art to undertake its application with greater certainty of desired results.

From the data that have been collected on power transmission in industrial shops, much of which is to be found in the transactions of the various engineering societies and in the magazines, it appears that if a certain maximum horse-power is required by all the tools of a shop, say 100 h.p., it will require at least 100 h.p. additional to transmit this effective power by belts and shafting. This loss of 100 h.p. remains constant whether the effective horse power is reduced or not. This means that 200 h.p. must be generated. Should these same tools be driven by individual motors, instead of 100 h.p. being required for transmission only 43 h.p. is required, even if every tool is running; but it is found that in the average industrial shop every tool is not running at the same time, some being shut down and others operating on lower than maximum speeds, thus requiring less horse-power. It has been determined practically that in the ordinary manufacturing establishment the mean

effective power is but 30 per cent. of the aggregate effective power which is required when all the tools are running at maximum load. This percentage is termed the load factor. In the case of belt-drive there is, then, 100 h.p. assumed loss for 100 h.p. effective load; that is, an efficiency of 50 per cent. Applying the load factor as above, it is found that there is but 30 mean h.p. to use and that it requires 100 h.p. to transmit it, thus giving the real efficiency as only 23 per cent. With the individual motor drive the loss varies with the load. Taking the same load factor, and assuming 30 per cent. as representing the loss incurred by the 30 h.p. effective load, there is but 13 h.p. loss against 100 h.p. with the belt drive. Thus, with individual drive, there is generated 43 h.p., of which 30 is effective, giving an efficiency of 70 per cent. against 23 per cent. by the shaft and belt method.

In a paper read by the author before the New York Electrical Society in November, 1901, it was shown that, assuming steam power to cost \$36 per horse-power per year (or 3,000 hours), with the shaft and belt system the power would amount to two per cent. of the cost of the establishment's product. With sub-divided motors it would be one per cent., and with individually driven motors it would be something less than 4/10 of one per cent. of the cost of the product; so that, assuming a plant with an output of \$1,000,000 a year, the following statement results:

Method of Drive.	Cost of Power.	Yearly Saving.
Belts and shafting . . .	\$17,000.00	
Sub-divided motors ..	8,500.00	\$8,500.00
Individual motors. . .	4,000.00	13,000.00

It appears from such information as the author has been able to obtain since that time, that the above figures are correct. These data relate to the average machine shop, and not to establishments run under conditions peculiar to their line of work, and which must be put in a class by themselves, the law of averages being applied to their peculiar conditions.

Assume that in the average machine shop 60 per cent. of the motors installed are to have variable speeds. These variable speed motors will have a rated capacity considerably higher than the average amount of power they will be called upon to supply. Assume that the rated capacity of the other 40 per cent.

represents the exact amount of power that they will consume—and this assumption is justified because their speed is not varied. Of the sum of the total rated capacity of the variable speed motors and that of the constant speed motors, 35 per cent. fairly represents the mean power that all of these motors will be required to furnish, if they are all running at the same time. This mean power, of course, varies with that percentage which the variable speed motors bear to the total installation. If the load factor of 30 per cent. be now applied—which provides for the shut down of tools and reduction in the power due to slow speed—it is found that the average power that must be provided by the generating plant is but 10.5 per cent., of the aggregate *rated capacity* of the individual motors installed. While it is true that 60 per cent. of the motors have a much larger rated capacity than is actually required, still this very small amount of power required is an evidence of the remarkable efficiency of the individual drive system. It cannot be assumed that this 10.5 per cent. is the capacity of the generating plant required, because provision must be made for maximum conditions, and inasmuch as that percentage represents but a mean condition. However, the system is so efficient that ample margins of say 100 or 200 per cent. can be applied, which may also provide for "stand by" purposes. And yet the purchaser who applies this individual motor system comes well within that power plant which he would otherwise have to supply to meet the mean conditions of a belted plant, without providing any "spares" for the latter. The author feels that if it were not for the empirical data presented time would be wasted in stating an already well accepted fact; *i. e.*, that the individual motor drive is highly efficient, and many times more so than the old system of belt transmission, or its modification of belted motors in groups. It is not claimed that the latter itself has not a sphere of usefulness and that a large one, the foregoing being merely a comparison of the relative economy of these different systems.

It would not be possible to use the individual motor, if means were not available for successfully varying its speed. To control the speed of a motor it is necessary to apply to the armature terminals a voltage corresponding to the speed desired. This can be accomplished in several ways:

The Rheostatic Method.—In this case the current is generated at any ordinary source of supply at a fixed voltage. Before reaching the motor, it is passed through a resistance which

is adjusted to consume just so much of the voltage as will reduce the speed of the motor to the point desired. This method has three limitations, viz.: (a), that if the load put upon the motor varies, the proportion of the voltage consumed in the rheostat is altered, and this changes the speed of the motor, which may not be desirable; (b), the system is inefficient, because that percentage of the voltage which is consumed by the rheostat represents a dead loss; and (c), the dimensions of the rheostat necessary to dissipate the energy may reach an inconvenient size.

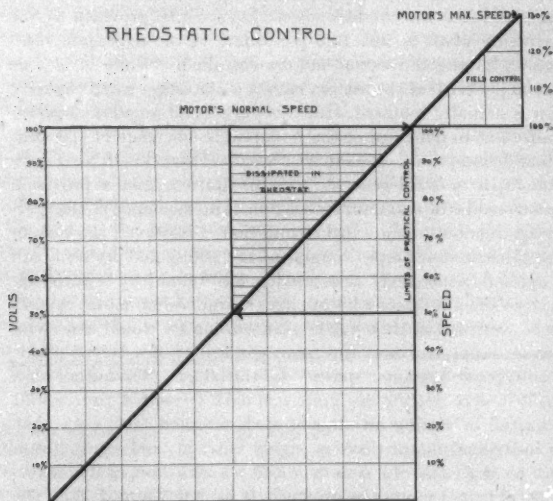


Fig. 1.

Within its limitations, however, the rheostat system of control can be made very useful. Fig. 1 is a diagrammatic representation of this system. It will be seen that the motor cannot be reduced from its normal speed more than 50 per cent., because below that point the fluctuations in speed, due to variations in torque, are too great.

Multi-Voltage Method.—This method consists essentially in supplying the motor with as many different voltages as are necessary to cover the desired range of speed. In its simplest

form this method consists of generators, each adjusted for different potentials. This, however, is not necessary, because it has been found that where several motors are involved they will balance up against each other in such a way as to divide amongst themselves the full voltage, so as to give the respective desired speeds. It is, therefore, only necessary to supply the main generating plant with a small balancer to take up any differences that there may be. By dividing the voltage at three points, there are six possible combinations which successfully cover the full range of speed as far as general requirements

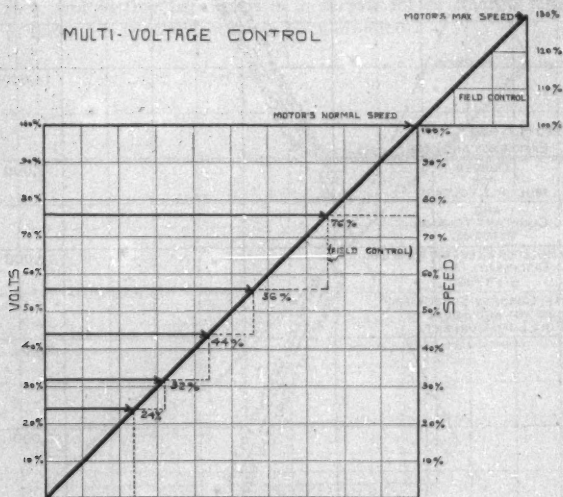


Fig. 2.

are concerned. The advantages of this system are: (a) that any one of the lower steps can be maintained constantly and quite independent of variations in the torque or load upon the motor—this is absolutely essential to successful tool operation; (b), that the system is highly efficient; (c), that appliances to control it are of very small dimensions and convenient to operate (see Figs. 2 and 3).

Special Methods.—In this class are to be found various methods which have been devised to meet the special requirements of

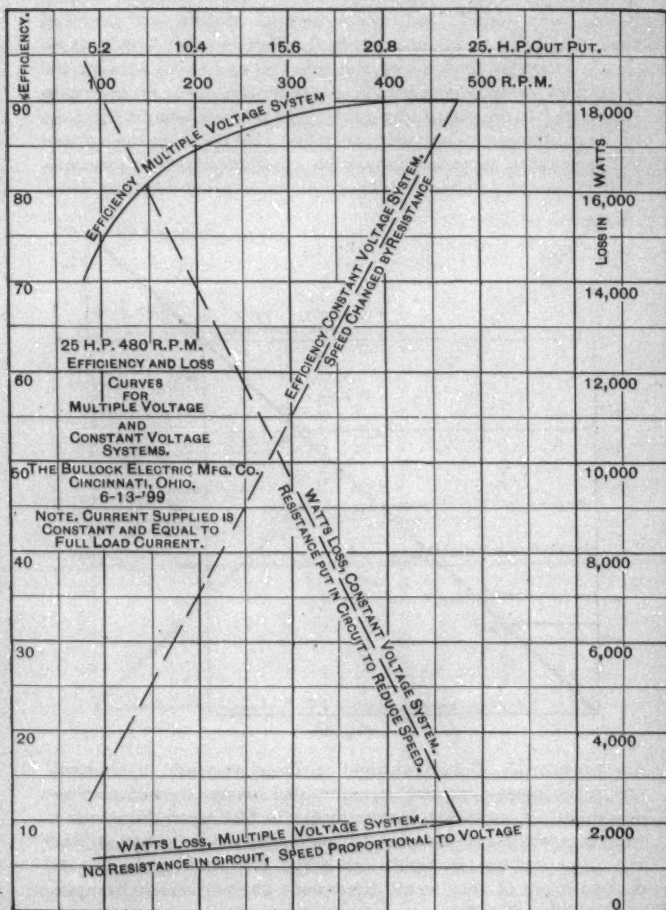
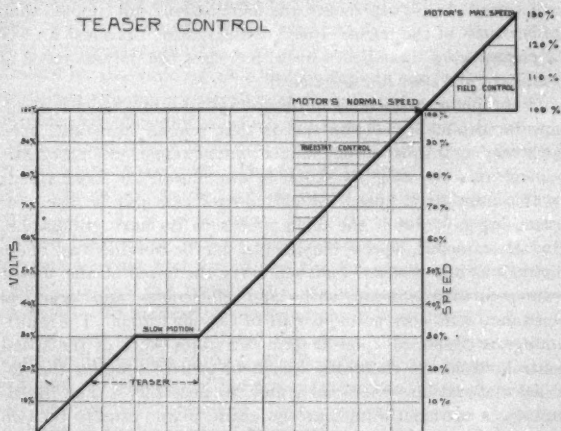


Fig. 3.

some one power application. Among these is the teaser system. Fig. 4 represents a system designed to take care of unusual conditions, such as are to be found in the operation of large printing presses. In such cases the motors can also be operated at a very low rate of speed. The method consists essentially in employing a small motor, which takes current from the main source of supply at the full voltage. This motor drives a small generator wound with large current capacity, and this current it supplies to the main working motor, but at low voltage, because the speed is very slow. It is because of the latter fact, and further because it is in service for so small a space of time, that the apparatus can be made small.



Field Control.—The foregoing methods vary the voltages applied to the terminals of the motor armature. There is a method of changing the speed by varying the field strength of the motor and in that way changing the counter electromotive force at a given speed e.m.f. This has two limitations: (a), the first one met with in practice; viz., that as the field of the motor is weakened it goes farther and farther off from its electric balance, and its distress is soon evidenced by sparking at the commutator, due to reaction of the armature upon the weakened field; (b), the torque will fail, if the field is weakened beyond

a given point. In a motor designed to come fairly well up to the limitations of its normal rating, the speed should not be increased more than 30 per cent. If, however, the motor is large for its work, *i. e.*, under-rated, according to commercial standards, then of course its speed can be increased until the limiting conditions of speed control, as established by its rating, are again reached. Or if the motor is operating at a lower potential impressed upon its armature than that of its normal rating, its speed may be increased over a larger range by weakening its field. But, generally speaking, it is well to understand that field control, while most useful within its limitations, cannot be successfully carried beyond such limitations and that such limitations represent an increase of not more than 30 per cent. of the normal speed of the motor. It must always be remembered, that field control increases the normal speed of the motor and does not decrease it.

In combination with the multi-voltage system—which is available for producing certain speeds that remain constant, even with varying torque, throughout the entire range—the rheostatic control can be used for reducing any one of the fixed speeds to the next fixed speed. Field control can also be used for increasing any one of the fixed speeds to its next graduation. By these means, speed increments can be obtained as finely divided as one pleases, that will carry the speed of the motor from zero to maximum, with high efficiencies and practical constancy at any one point, in spite of varying torque. The multi-voltage is depended upon to form the frame work of the speed control, while the rheostatic and field control supplies the detailed elaboration, where such may be necessary. The multi-voltage is carried throughout the entire plant, usually by two conductors in addition to the two main circuits, while the rheostatic and field control is applied locally as circumstances may require.

Thos. A. Edison marked an important epoch, when, about seven years ago, in his great ore milling undertaking, he put into operation a principle that had long been accepted by him;—that machinery and equipments are cheaper than labor and general expense and that it is better to use up the machinery at a high rate, if by so doing the output is materially increased.

About four years ago the matter of determining exactly the speed limitations of iron working machinery was taken up by

a few enterprising engineers, and these limits have since been kept in view with the greatest amount of success. Where formerly the old thumb rule governed, the slide rule is used. While labor was bitterly opposed to the principle of the employer inducing his operators by additional incentive, to work up to the highest efficiency—which incentive was withdrawn when that point was reached, and their wages perhaps, still further reduced, should they fall behind—it has been led to recognize the benefits to be obtained by securing to the operator his mean wage, and allowing him to share in the benefit gained by his working up to his normal capacity. These methods at present come within two general classifications. I will mention them here, because they are pertinent to the general subject of variable speed control. The first is the premium system, in which the law of averages is applied to past work and the result is taken as a standard for determining what can be done in the future. This determined amount is generally cut down in order to provide for the increased efficiency at which the man is supposed to work. Now, if a man is able to improve upon that time, he is given a pro rata share of the gain. This system is based upon empirical data. The other system is more recent and is known as the bonus plan. It is as follows: First, the limit of speed and depth of the cutting tool are determined, then the area to be traversed by that tool determines the minimum space of time in which the tool can traverse it at its maximum cutting speed and depth. In making this calculation, it is assumed that the operator has always available the speed that represents the maximum limitations of the tool. Stability of the machine tool itself, and the capacity of the power transmitted to do the work, must be carefully considered. The operator is given explicit directions as to the shape of the cutting tool, the feeds, speeds and general method to be applied in doing the work and the exact time involved in such method is also given him. These instruction cards are not only theoretically correct, but state conditions that can easily be obtained in practice. If the operator succeeds in meeting these conditions, he not only receives his regular pay, but is also presented with a fixed bonus. With such a method of operation as has just been described, the practical operator immediately recognizes the essential points.

1st.—He must have a cutting tool that will stand up to the work.

2d.—He must have a motive power having a range of speed

from which he can always select, and quickly, the speed that will produce the result expected. This motive power must be able to stand up to its work.

3d.—The machine tool must have sufficient strength to stand the strains that may be put upon it.

The limit of high speed operation is not to be found in cutting tools, or in the ability of motors to successfully do the work and to vary their speed, or in the motor's first cost, but is to be found in the stability of the machine tool itself, which is generally designed to stand the lower strains and the smaller powers required by the old cutting rates. I have prepared a table which I believe fairly well represents what was possible in the way of cutting speeds, four years ago, and what can be readily obtained in practice to-day, provided the machine tool can stand the strain.

CUTTING RATE.

(Revolving.)

Material.	By old Methods.	New Methods*	Cut.	Feed.
Cast iron.....	20 ft.	60-80 ft.	$\frac{3}{8}$ "	$\frac{1}{8}$ "
Forged steel, unannealed....	12 ft.	40-60 ft.	$\frac{3}{8}$ "	$\frac{1}{8}$ "
Steel casting.....	10 ft.	40-70 ft.	$\frac{3}{8}$ "	$\frac{1}{8}$ "

*Using Novo, Taylor White or Firth Sterling Tool Steel.

It is interesting to point out in connection with this table, that at these high cutting rates, a speed range must be provided to allow for the variation in the material itself and therein the variable speed motor, with its large range of easily selected speeds, serves a most important function.

The Bickford Drill & Tool Company give some interesting information as to progress in increased cutting speeds for drills. While two years ago the speed ranged from 9 to 188 revolutions and the feed ranged from .005" to .007", they are now enabled to drill a $\frac{3}{8}$ " (.375") hole at a feed of $\frac{1}{16}$ " (.06") per revolution.

Upon the conclusion of the paper Mr. Lozier said:

Your President in his opening remarks said that the mechanical engineer had put upon the electrical engineer the responsibility of applying the system of varying the speed of motors. He pointed out that while the problem appeared to be a mechanical one, it was really an electrical one. This is true. What I par-

ticularly wish to point out in this paper is the close relation that the individual motor with its variable speed drive, bears to what is now known as the new shop method.

When I refer to it as "method," I probably ought to say "methods," for there are a number of means for increasing shop production. These methods were first evolved, probably not more than four years ago. Perhaps Edison was one of the first to enunciate the principle that it is better to waste the tool if you can save your labor. He put this theory into practical operation in his large cement works; and I know that for years he has always worked to the end of increasing his product as being the most practical means of increasing his profit.

Experiments were made beginning some four years ago at one of our largest steel works, and thousands of dollars were expended in experimenting, not only with cutting steels, but also with variable speeds. It was found that the general machine shop practice was far, far behind its possibilities. Under the old methods, the man who had served his apprenticeship was turned over to the blue print and stock and by the rule of thumb he got the best out of the stock that he could. Modern tools, instead of applying the thumb rule, apply the rule best adapted to the work, and increase the output from 100 to 200 per cent., and in some cases to 300 per cent. This is an enormous increase. It means that a shop which has been in the habit of working day time and night time, can increase its output by working only day time, and shutting off its night force. It means that if America applies these new shop methods and the old countries do not, the old countries will be left behind; they cannot hold the pace we will set for them. I was told two weeks ago by the superintendent of one of the largest shops in this country that by variable speed motors they increased their output over 40 per cent, and so I say that the variable speed motor bears an intimate relation to the new shop methods.

I think the mechanical engineers have not been disappointed in placing upon the electrical engineers the responsibility of introducing the new methods of tool operation.

There are one or two specific points I should like to bring up. What is involved in a multi-voltage circuit? The multi-voltage circuit involves a given source of supply—isolated plant or central station—having two wires. It then involves a balancer. The balancer is not as is generally supposed, a large device, having a capacity sufficient to carry all the motors at the lowest speed, any more than a life insurance company is organized and premiums adjusted on the basis of all the policy holders dying the same day. The larger the number of tools driven, the smaller the balancer may be; and we have taken it as a rule that the armature of a multi-voltage balancer need not be larger than sufficient to operate the largest single motor on the circuit at its lowest speed. This rule is borne out in practice in a number of cases.

If I may have the screen for a moment, I will show you what

corresponds to the multi-voltage balancer. This picture is a shop operated by individual motors, in which you notice the clear head room, and the other is a shop in England driven by belts. I think we are all so familiar with the advantages of individual driving that the pictures perhaps are not necessary. The next picture illustrates a multi-voltage balancer. There would be one commutator here, another there, and the third commutator would be at the other end. The next picture will show the connections of the circuit. In this particular case we have voltages of 60, 80 and 110, giving a total of 250 across the circuit. The interesting point in distributing the load on these circuits, is that if the motor is on 60 volts, it does not require more power than is passing through the balancer circuits. It acts as a shunt. As the power on the motor is increased, however, less and less current passes through the balancer and more passes through the motor.

THREE-WIRE SYSTEM FOR VARIABLE SPEED MOTOR WORK.

BY N. W. STORER.

A description of the operation of variable
speed D.C. motors on the three wire system.
Illustrated.

At the present time, when the possibilities of the electric motor are being realized and it is everywhere taking its place in factories, machine shops, steel mills and in practically every kind of industrial enterprise, the type of motor to be used and the best method of applying its power are much discussed topics in engineering circles. In deciding the type of motor to be used it is generally recognized that the alternating current induction motor has its own particular field; the D. C. and A. C. motors have a common field, and the D. C. motor in turn has its own special field. In deciding the method of applying the power, the choice lies between a separate motor for each machine and group driving of machines from counter-shafts driven by constant speed motors. If individual motors are selected, when variable speed is desired, there is the further choice between the constant speed motor with mechanical speed changing devices and a variable speed motor direct connected to the machine. In this latter class of work is found the special field for the D. C. motor.

Omitting cranes, street railways, hoists, and other classes of service where the series motor with rehostatic control is used, we find that variable speed motor work may be divided into three classes:

(1.)—Machines requiring a torque increasing with the speed. Blowers and fans belong in this class. The power required for the machine increases very rapidly as the speed increases and

great care should be exercised in selecting motors for such service. However, as the variation required is usually small, the requirements can be met with standard motors on a single voltage system. Motors should preferably be compound wound and the speed should be varied by means of a resistance in the shunt field.

(2.)—Machines requiring a constant torque. In this class pumps and air compressors are the most conspicuous examples. The speed variation required for such service is usually small and it is generally best and most economical to supply compound motors and to vary the speed by means of the shunt field rheostat, as in the case of the fans and blowers. A series winding is especially beneficial for this class of work in preventing the heavy fluctuations of current that would take place with a constant speed motor in passing through the different parts of the cycle. A compound motor may be used for this work because a constant speed at any point on the controller is not necessary.

(3.)—Machines requiring approximately the same maximum output at any speed, or a torque varying inversely as the speed. This class includes most of the machine tool work where automatically constant speed regulation on any notch of the controller is especially desirable. It is, therefore, necessary to use a shunt motor having good inherent regulation.

It is the last named class of service that has caused the most discussion. Several companies have entered this field with different systems of variable speed motor control. Some of these companies are able to place their motors on the standard and well-known systems of power distribution, while others seek to introduce special systems. The writer has been interested in the development of the three-wire system for this class of work, and it is the purpose of this paper to describe its operation and advantages.

The Generator:—The standard Edison three-wire system for general power distribution is so well known that it is unnecessary to describe it. The power station equipment, consisting of two 125 volt generators connected in series with the neutral wire brought out between them, is also well known and the single voltage generator with a motor-generator set of sufficient capacity to carry the unbalanced current, is used in many places. But the type of generator which is rapidly attaining prominence is the so-called three-wire generator, consisting of a standard d. c. generator designed for the maximum required e.m.f. having

collector rings connected to the armature winding like a two-phase rotary converter. The leads from these rings are connected to auto-transformers or balancing coils, the middle points of which are connected to the neutral wire. With no external devices whatever, the neutral wire is thus maintained at a voltage midway between the outside wires of the system (see Fig. 1). These generators may be operated in multiple with any standard three-wire system, whether it consists of two machines operated in series, a single voltage generator with a balancing set, or a

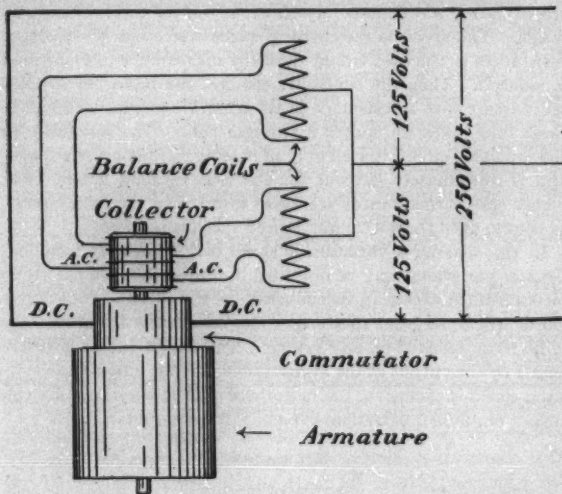


Fig. 1

double commutator generator. Any standard single voltage system may be changed into a three-wire system by adding collector rings to the generator and using balancing coils to supply the neutral wire.

The Motor:—The standard type of motor is used on this system. If only a small variation in speed is desired, as about 2:1 or less, only one voltage is used and the speed variation is secured entirely by changing the shunt field current. If wider variations

are required, it is preferable to use the two voltages of the three-wire system. It is necessary simply to make a 220 volt motor connected so that it may be operated on either 110 or 220 volts. The minimum speed is secured on the 110 or low voltage circuit with full field strength. Any other speed less than double the minimum will be secured on the same circuit by decreasing the field current. All higher speeds are obtained on the 220 volt or high voltage circuit in the same manner. Operated in this way the motor is started on the 110 volt circuit, having in series with the armature a resistance, which is cut out for the first running notch. The speed is increased in successive steps by inserting resistances in the field circuit until the maximum 110 volt speed is reached. Then the controller changes the motor to the 220 volt circuit with a resistance in its armature circuit, and at the same time gives the motor a stronger field. The resistance in the armature circuit is used only in passing to the higher voltage, and is immediately cut out for the first running notch. For higher speeds, resistances are again inserted in the field circuit, as before, until the maximum desired speed is reached.

In this manner a variation in speed of 1:6 is easily obtained. Greater variations may be obtained if desired, but are not to be recommended except in special cases, as the size and cost of the motor will be so great that larger variations than 1:6 are hardly to be recommended on any system. The size of motor is determined by the output at the lowest speed, so that unless the maximum speed is excessive, the motor size will be very large for the output required if variations even of 1:6 are required.

OPERATION.

Commutation:—The operation of motors on this system is most satisfactory. The fact that the speed is increased so much by weakening the field might lead some to think that the commutation would suffer, but such need not be the case. An example will demonstrate the truth of this statement. A certain machine requires a 5 h.p. motor to operate it with a speed variation of 1:4, say from 375 to 1500 r.p.m. On the three-wire system this motor will be a standard 10 h.p., 220 volt motor operating normally at a speed of 750 r.p.m. Run with full field strength on the 110 volt circuit, it will develop 5 h.p. at about 375 r.p.m. Operating on this circuit, which has only half its normal voltage, the motor will easily stand an increase of speed 60 per cent. to 75 per cent., bringing the speed up to 600 or 650 r.p.m. When it is changed

to the 220 volt circuit, it will have its normal capacity for 10 h.p. at 750 r.p.m.; but only half load is required and it will commute this as easily at a speed of 1500 as it would 10 h.p. at 750, because both field strength and armature current will be divided by two. From this it may be seen that when the motor is running at full armature current, the voltage is only one-half the normal voltage. When the motor is operating at full voltage, the armature current is only one-half the normal current. If speed variations of 1:6 are required, they can be secured by a very slight increase in the normal field strength of the motor.

Regulation:—The performance of the motor in speed regulation on the separate controller points is very good. As the lowest voltage used is 110 volts, the proportion of voltage lost in resistance of motor, brushes, armature, controller and wiring will be very much less than it would be if a minimum voltage of 60 were used, consequently the speed regulation will be much better. On an extremely slow speed motor the resistances of the different parts of the circuit play a very important part in the speed regulation. Where a very low voltage is used the speed variation from no load to full load may be as much as 20 per cent. or 25 per cent.

Controller:—The smoothness of operation in changing from one speed to the next is very noticeable. The field strength changes very gradually no matter how suddenly the field resistance is changed. Consequently, there can be no sudden change in speed. In this respect it is better than a system which changes the speed by changing the armature voltage without a resistance in the circuit. At the only point where the armature voltage is changed on the three-wire system, a resistance is inserted in the armature circuit, which effectually prevents a sudden jump in speed.

EFFICIENCY.

Motors:—The efficiency of the motors, as well as of the entire system, is high. Operating on the low voltage, the motor is at all times running under full load conditions with the efficiency increasing as the speed increases, because the field current and core loss are decreased at the higher speeds. When operating at 220 volts at the minimum speed, the efficiency corresponds to the half load efficiency of the standard motor. As the speed is increased, the copper loss in the armature remains constant and the field loss and core loss decrease so that unless the increased friction over-

balances them, the efficiency will increase up to the maximum speed. This is in marked contrast to a motor operated on a system supplying a different armature voltage for each speed. To fill the requirements of the above case on the multi-voltage system, a motor of the same weight but normally rated at 20 h.p., 220 volts and 1500 r.p.m. will be required. It will operate at a voltage of about 60 at minimum speed and will there require the normal full load current of the motor to develop 5 h.p. This would be double the current of the motor operated at 110 volts at the same speed; and while the copper loss in the armature and field and the core loss would be about the same as in the other motor, the loss in brushes would be doubled and the loss in controller and wiring very much greater. An increase in the speed will increase the core loss very rapidly, the field will remain constant and the copper loss in the armature will decrease. The efficiency of this motor may be explained by the statement that at the only time the motor is operating under its full load armature current, it is running at 60 volts and the efficiency is necessarily low. At the maximum speed where the normal voltage of the motor is reached, it operates at only one-quarter load and consequently with a low efficiency. At no point on the curve does its efficiency equal that of the motor on the three-wire system.

Transmission.—The efficiency of transmission on the three-wire system is high. Practically all of the current is transmitted at the maximum voltage, as the motors are equally distributed between the two sides of the system for their low speeds. The chances for unbalancing are thus very much less than on a multi-voltage system that requires all of the motors to have corresponding speed notches on the same circuit.

Generating Plant.—The efficiency of the generating plant is also a maximum. The three-wire generator itself has the same efficiency as the standard d. c. generator of the same capacity. The losses in the balancing coils with 15 per cent. unbalanced load will not exceed one-quarter of 1 per cent. of the capacity of the generator. This gives the most efficient type of three-wire generating apparatus. Comparing it with the complicated generating outfit required for a multi-voltage system, shows at once its superiority, both in efficiency and in the amount of attention required in operation.

Economy.—The three-wire system is very economical in the wiring. As practically all of the current is transmitted at the higher voltage, the neutral wire may be very small. In this respect also, it is superior to the multi-voltage system. The

latter really has two neutral wires, but as the unbalancing is likely to be much greater, they must necessarily be larger than the neutral of the three-wire system, and all the wires would be larger if the same percentage of line loss were maintained. Branch lines to the motor, forming a considerable part of the total wiring system, must be much heavier than on the three-wire system as there are more wires, heavier currents to be carried and greater losses.

Controller.—The controller of the three-wire system is very simple. It is of the standard drum type, designed mechanically like a street car controller. It has the field and armature resistances in the base, making the whole controller very simple and compact.

The advantages of the system described in the foregoing may thus be summed up as follows:

(1.)—Simplicity, not only in the generating plant, but in the transmission lines, motors and controller.

(2.)—Efficiency in generating plant, transmission line and motor.

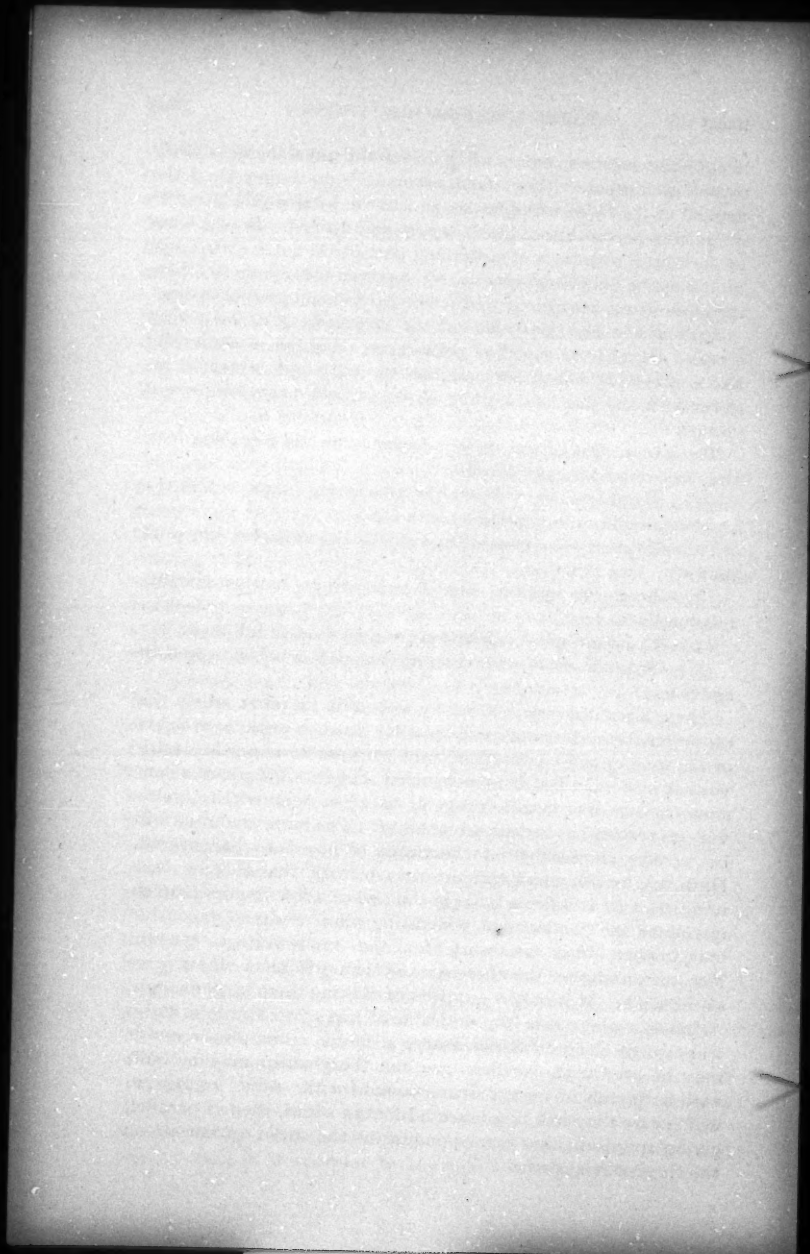
(3.)—Economy in first cost of generating plant and transmission lines.

(4.)—Constant speed regulation from no load to full load.

(5.)—Smoothness of operation in changing from one speed to another.

These advantages are all easily apparent for work where the motor output is the same at all speeds. In such work the weights of the motors will be practically the same as those on the multi-voltage system. But it is recognized that in work where a constant torque over a wide range of speed is required the multi-voltage system has certain advantages. The motor required will be smaller, depending on the range of speed to be covered. However, for the small amount of such work that is to be done it is better to sacrifice a little in the size of a few motors than to introduce the complicated generating plant and the expensive transmission lines necessary for the multi-voltage system. Motors running on the three-wire system will meet all such requirements. It is only a question of making them large enough.

In cases where it is impracticable to have two voltages, and a wide range of speed is necessary, a double commutator motor may be used with excellent results. This motor may be built with both ends of the armature wound for the same voltage, in which case they will be connected first in series, then in parallel, giving speed changes corresponding to the speed variations on the three-wire system.



THE STORAGE BATTERY AS A FACTOR IN SPEED CONTROL.

BY H. B. COHO.

A description of the use of storage batteries
in connection with the operation of printing
presses and with the multiple voltage system.

In presenting this paper to the INSTITUTE, nothing very new or novel in the idea of varying the voltage across a battery, in order to secure speed variation is claimed. There seem to be some differences of opinion as to the rights of different persons to the multiple voltage system of control, and this opportunity is taken to call attention to the part which the storage battery may play in this important work. The many short comings of the storage battery are appreciated, but recent experience has taught that while the watts per pound of material have not been so materially increased in recent years, the life of high grade storage cells has been increased to such an extent that the old ideas as to cost of maintenance will have to be modified, and the charges of 10 per cent and 15 per cent of first cost per annum for renewals must be cut in half.

All are no doubt quite familiar with the various ways in which batteries may be utilized, and it is the purpose in this paper to dwell particularly on a method of using a storage battery as an auxiliary or independent source of supply in connection with the operation of printing presses.

With printing press work, the operations of making up and threading in paper require a positive fixed speed of from 12 to 20 r.p.m. on the main shaft of the press. The methods of obtaining this speed from electric motors, which are common, are to em-

ploy either fixed resistances, armatures in multiple and series, or separate sources of supply, such as motor-generators. The motor in the last case is a shunt machine, wound for the line voltage, while the generator is a shunt machine with field separately excited from the line and supplied with a constant voltage. The armature is wound to give a fixed voltage from 12 to 40 volts, depending upon the special requirements.

It is in connection with this last system that the method mentioned in this paper is particularly applicable. Fig. 1 shows the connections to the storage battery and to the motor through the controller. The following data have been obtained in connection

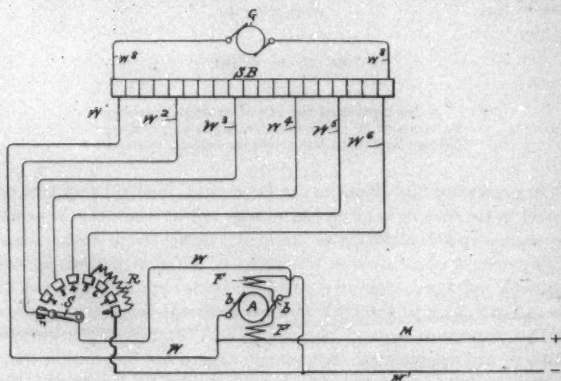


FIG. 1.

with the utilization of this system for the operation of quadruple Hoe printing presses of moderate size. These presses operate at 12 r.p.m. in making up and threading in, and require for this purpose a current of 150 amperes at 40 volts. The threading in and making up process per press lasts at a maximum not more than ten minutes. This process has to be repeated not more than fifteen times in twenty-four hours. From these data it is apparent that a 200-ampere-hour battery on an hour rating will more than fulfil the requirements.

A battery of accumulators to give 40 volts and 200 amperes for one hour will cost not more than \$400, which is not a prohibitive figure, especially when considered in connection with the following additional advantages:

(a).—One battery will do for a number of presses, for the reason that all of the presses in any establishment are not simultaneously in operation.

(b).—The battery can be on charge at a very low rate at all times when current is flowing on the mains, thus insuring the best possible results from the battery at a minimum cost for current.

(c).—The battery having no moving parts, such as bearings and commutators to get out of order, will doubtless appeal to the press operators.

(d).—The e.m.f. of a battery is constant, while that of any other independent source of supply is variable, depending upon the line voltage. Many a press operator has lost his fingers because of sudden variations of voltage supplied to the motor.

The operation of elevator motors by means of a storage battery placed directly across the line, and in connection with a multiple series controller, offers an excellent means of varying speed. The battery can be figured on a two-hour rate in the severest service, so that the first cost is not excessive, while the saving from repairs to resistance plates and contact pieces is a matter of no small importance in comparing the economic advantages of two systems.

The use of a battery for the multiple voltage operation of machine tools, presents another phase of the subject. The high first cost of batteries militates against their adoption. In a shop requiring about 100 k.w. average motor load, the battery capacity will have to be calculated on a three-hour rating. The first cost will be about 30 per cent. more than that of equivalent multiple voltage generators as now employed. That the battery is 30 per cent. more expensive in first cost does not, however, exclude it from competitive consideration, because the increased efficiency of the cells over that of multiple voltage generators when operating at varying loads.

As a substitute for storage batteries one can often use so-called counter electromotive force cells. These may be constructed with unformed lead electrodes in an ordinary battery electrolyte. The necessary electrode surface is not determined by the ampere-hour capacity of the plates, but by the internal resistance requirements for economic operation. The cost of construction of these cells is much less than that of equivalent batteries. The cutting down of supply voltage by counter electromotive force is the natural method dictated by economic consideration, while to cut it down by resistance is unnatural.

Referring to the above paragraph, it is probable that careful examination will prove that the c. e. m. f. method of multiple voltage control, taken in connection with the weakening of the field of motor to give the last 25 per cent. speed variation, will result in the most economical system to operate and the lowest first cost for installation.

ELECTRICALLY OPERATED COAL HOIST. HAVING VARIABLE SPEED CONTROL.

BY P. O. KEILHOLTZ.

A description and data concerning the
operation of a coal hoist. Illustrated

The use of electric machinery for coal hoisting has many advantages over steam machinery when the hoist is considerable. It has also the advantage of less cost of operation and maintenance. Its initial cost, however, is greater.

There are two distinct operations in coal hoisting: raising the loaded shovel and lowering it empty. All that is required for raising is a smooth acceleration for closing and raising the shovel, and full power application as long as possible in order to decrease the time of hoisting. Full power application can be continued longer with an electric hoist than with steam, owing to the less inertia of the former. A smooth acceleration is required because the cables are without stretch and for very high hoists would introduce objectionable strains in the structure or damage to the gearing. It is in lowering the empty shovel that the electric hoist has marked advantages. With steam hoist the lowering is accomplished by braking, and with high hoists, large shovels and rapid lowering the large amount of heat generated by the brakes is difficult to get rid of. As brakes depend upon friction, which is a function of two things—the surface conditions and the pressure between the rubbing surfaces—the amount of friction is uncertain, and braking, therefore, is objectionable because violent surgings are introduced in the boom structure and tower. With the electric hoist, owing to the perfect reversibility of the electric motor, the motor is used as a generator having a separately excited field and driven by the weight of the descending bucket. In its armature circuit is a rheostat to dissipate the heat generated. It is at once apparent

consists of a motor generator set and a hoist motor which receives its power from the motor generator set, the motor of which is supplied with 550 volt direct current. The field of the generator,

is separately excited and its strength is controlled by the operator by means of a foot operated rheostat. The field of the hoist motor is excited by the 550 volt, direct current. By means of a double throw, three-blade switch the foot rheostat is cut out of the generator field circuit and cut into the field circuit of the hoist motor; and the armature leads of the hoist motor cut from the armature circuit of the generator to the rheostat.

Appended will be found sketches of coal hoisting tower, wiring diagram, distance-time curve and a velocity curve, together with data of test and other particulars.

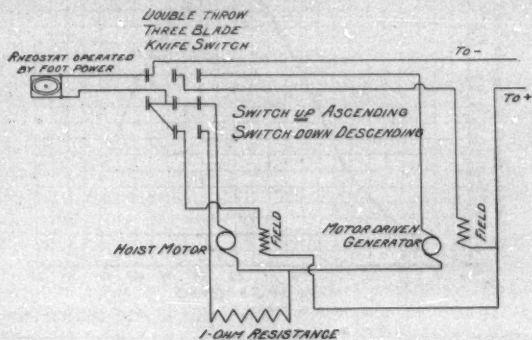


Fig. 2.

Weight of coal hoisted, average of 7 shovelfuls.....	lbs. 2,330
" " shovel empty	" 2,907
Total weight, lifted exclusive of weight of ropes	" 5,237
Average lift	feet, 126
Readings of main motor.	
Volts.....	540
Average current in amperes to close shovel	57
Maximum " " " " " "	73
Average " " " " raise loaded shovel.....	189
Maximum " " " " " "	243
Field current, not included, in above, 2.8 amperes.	

From the velocity curve (ascending) it will be seen that it took 11 seconds to close the shovel, and from the distance-time curve 26 seconds to close the shovel and raise it to the dumping hopper. Therefore, 15 seconds is the time taken to raise the loaded shovel; and as the lift is 126 feet, the average velocity is 8.4 feet per second.

The efficiency is,

$$\frac{8.4 \times 5237}{189 \times 540} = 58\frac{1}{2}\%$$

Performance test:

Coal lifted, tons, 101.86.

Time, minutes, 87.33.

Rate, 70 tons per hour.

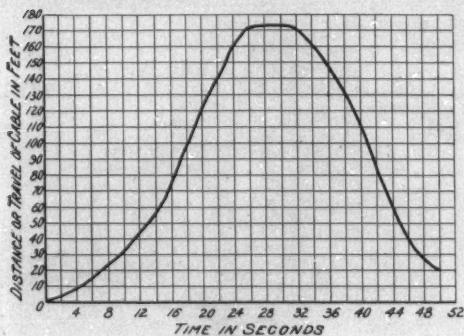


Fig. 3.

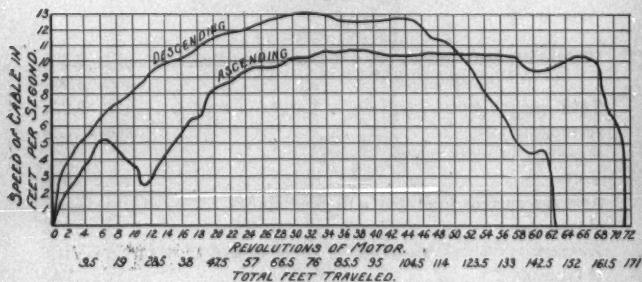


Fig. 4.

PARTICULARS OF ELECTRICAL APPARATUS.

Main Motor:

M.P., 6—150, h.p., 450.

Volts, 550.

Generator:

M.P., 6—85, k.w., 450.

Volts, 250.

Hoist Motor:

M.P., 6—100, h.p., 200.

Volts, 250.

A SERIES-PARALLEL SYSTEM OF SPEED CONTROL.

BY GEO. W. FOWLER.

A description of the parts of a system including a double commutator motor, switchboard controller, automatic switches and emergency switches. Illustrated.

The system of control of stationary direct current motors which I shall endeavor to describe to you has been quite extensively and successfully used for driving various kinds of machinery, especially large printing presses.

The component parts of the system are a double commutator type motor, a switchboard, controller, a pair of automatic solenoid switches, and a set of emergency switches. These are shown in Figs. 1, 2, 3, 4, 5 and 6. The motor is shown in Fig. 7.

The motor is of the ordinary slow speed, compound wound type, with the exception that it has two separate windings and commutators on the one armature body, operating in one magnetic field. The field windings are so arranged that the series turns can be cut out after starting, thus obtaining the advantages derived by using a compound wound motor at starting, exerting a powerful starting torque with a minimum amount of current; and the constant speed features of the shunt motor, by cutting out the series, after the motor has reached a certain fixed speed.

The armature windings are, of course, thoroughly insulated from each other, and have no connection excepting that obtained through the operation of the controller.

By an inspection of the controller, Fig. 2, it will be seen that it consists of numerous contacts and contact rings mounted upon a slate, the sub-structure carrying the controller arm, which moves over the contacts. For convenience, some external means is generally used to operate the controller, such as the lever shown in Fig. 3, which is frequently used in connection with

printing press work. It is through the movement of this one controlling lever, that all the combinations of windings and connections, with the resultant variations in speed, are obtained.

Upon closely examining the controller in Fig. 2, you will notice that the contacts appear to be divided in two separate divisions. To the left the contacts are sub-divided into many small ones. To the right there are but few larger ones. Those to the left are



FIG. 1

in use only when the armature windings are in series, while those to the right are in use only when the windings are in parallel. The two divisions have no connection with each other whatever. For use in graduating the speed, there are two banks of resistance used; one bank in circuit with the armature windings when they are in series and which is connected to the smaller contacts to the left, and another bank in circuit when the armatures are in parallel, and which is connected to the larger contacts, to the

right. The contact rings on the controller are in circuit with the shunt field of the motor, and the small round contacts for the purpose of interposing resistance therein for the highest speeds.

With any variable speed control system wherein a combination of windings or machines are used to obtain the speed variations, it generally becomes necessary at some point in the operation to open the circuit, preparatory to making some rapid change in the combination, in order that the speed changes shall be gradual. When performing this operation it has been, and now is, the custom to use magnetic blow out coils to prevent excessive flashing of the controller contacts. In the series-

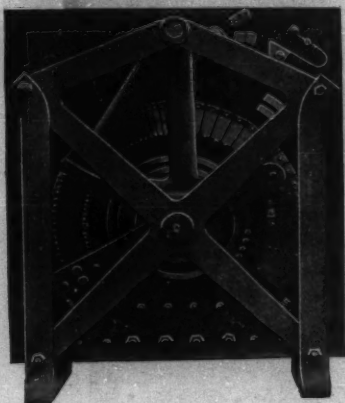


FIG. 2.

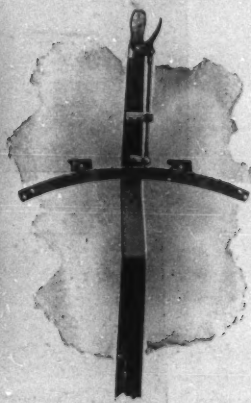


FIG. 3.

parallel system it is necessary to open the circuit when changing from series to parallel, for it is quite obvious that the windings cannot be in series and parallel at the same instant.

In this system of series-parallel control no blow-out coils of any kind are used and the change from series to parallel or vice versa, is obtained by the use of an "Automatic Solenoid Switch." A very good idea of the construction of the switch can be obtained by an inspection of Figs. 4 and 5. Two solenoids enclosed in a cast iron case, the object of which is to form a good path for the lines of force, are mounted upon one side of a slate. Through the centre of these solenoids is a plunger slotted in the centre

through which passes a small pin, thereby making a flexible connection between it and the shaft carrying the switch arm on the opposite side of the slate. When energized at the proper time, first one and then the other solenoid operates, throwing



FIG. 4.



FIG. 5.

the switch arm to the right or left, as the case may be. The connections of the switch jaws shown on the front of slate are such that when connection through them is completed by the switch arm, the armature windings on the motor are first in

series, and when the arm goes to the other side the windings are in parallel. Therefore, during the time when the switch is operating from series to parallel, the circuit is opened; the action being instantaneous, there is no noticeable change in the speed, neither is there the slightest flashing at the contacts of either controller or switches.

Two of these automatic switches are used with each equipment, one to perform the operation as outlined above, the other to "stop and start" the motor—that is, to open and close the circuit. There is no open point on the controller except between the series and parallel side, and when the lever is thrown to the position which is normally "off," the solenoid switch used for this purpose opens the circuit. Likewise, when the lever is moved "on," the switch closes the circuit. This absolutely

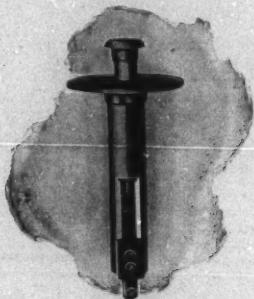


FIG. 6

prevents the slightest flashing at the controller contacts, when stopping the motor. By the use of the second mentioned switch, it is also possible to stop the motor from any one of several points, which is required in newspaper printing.

To accomplish this the emergency switch, Fig. 6, is used. This switch is so connected with the controller (see Fig. 9) that when the plunger is depressed, connection is made through the solenoid which throws the switch "off." In Figs. 12 and 13 is shown an improved type of solenoid switch, wherein one coil is used for each switch.

A reference to Fig. 8 will give a fair idea of the controlling device complete. Here the solenoid switches are mounted at the top, the controller and lever at the bottom. The circuit breaker shown to the left is of the "no voltage" and overload type.

In Fig. 9 is represented a diagram of the wiring and connection of a complete series-parallel equipment. A careful inspection will disclose the following conditions when the equipment is in operation.

With the controller lever "off," the two solenoid switches are in a position corresponding to "off," on the one and "series" on the other. The lever being moved to contact 2 (on controller) one solenoid switch throws "on," the other still remaining in a

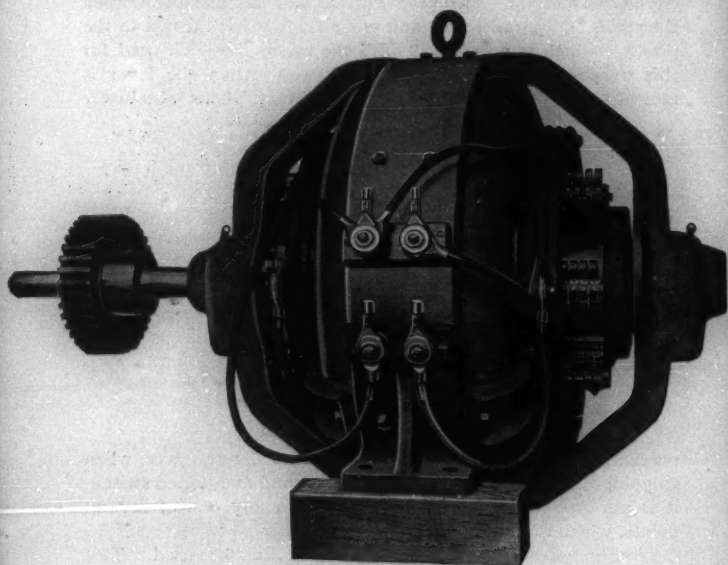


FIG. 7.

series position. The current then flows through the two armature windings, in series, in series with the series field and in series with the resistance connected between controller contacts 1 to 40. This gives the slowest speed obtainable, which, when used for newspaper printing, is 5 per cent of the maximum. The next successive moves of the controller lever, simply cut out resistance in the armature circuit, until contact 38 is reached, when it is all out. At this point the series field on motor is gradually cut



FIG. 8.

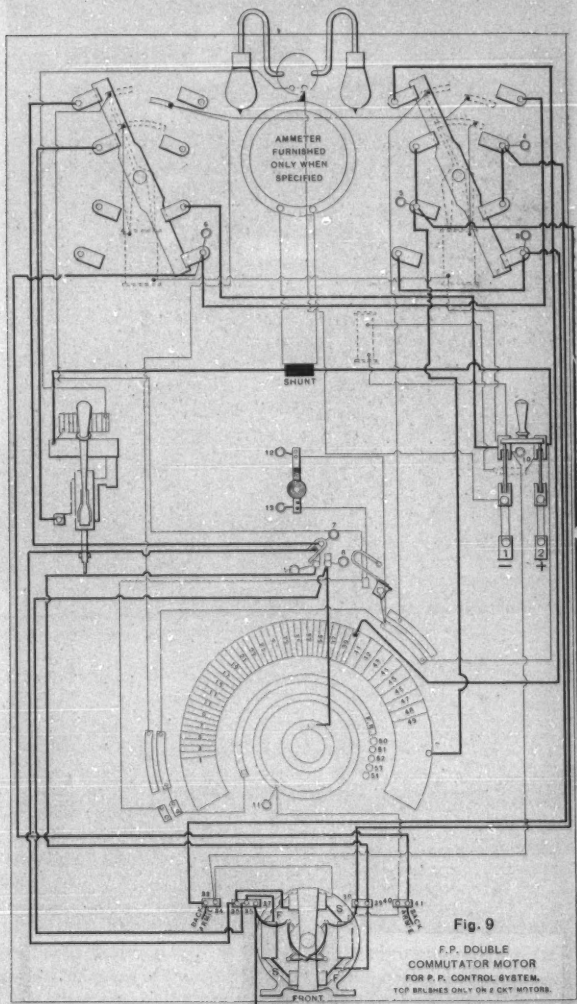


FIG. 9.

out. As will be noticed the series field is connected to terminals 7, 8 and 9 on the controller and permanently attached to terminal 7 is a small quadrant switch operating between two switch jaws, on 8 and 9. As the controller lever moves under 7, 8 and 9, the switch at 7 is engaged by the controller and enters switch jaw on 8. This short circuits one-half the series field coils on motor. Continuing the movement of controller, the switch enters switch jaw at 9, thus connecting 7, 8 and 9 and entirely cutting out the series field. Therefore, the motor is now running as a shunt machine, with the armature windings in series.

Now, as the controller lever is moved to cover contact 41 and 42, the solenoid switch previously mentioned is brought into connection and changes the armature winding from series to parallel. At the same time enough resistance is inserted in the circuit to keep the speed and current normal. (See curves, Fig. 10.) As the lever is moved over 43 and 44, etc., resistance is gradually cut out until 49 is reached, when the motor is running without resistance in the armature circuit and the windings are in parallel. There are still five more speeds, which are obtained by inserting resistance in the shunt field. At the last of these the speed of the motor is at its maximum. To stop, the emergency switch connected as shown on Fig. 9 may be operated, which throws the solenoid switch "off," thereby opening the circuit, and stopping the motor.

Before the above operation can again be repeated, the lever must be brought back to the starting point, when over contact 2, one switch is thrown back to "series" (that is so that it connects the armature windings in series) and the other switch "on." Then to continue as before would simply be to move lever from 2 and so on, or if to stop it altogether, move to contact 1, where the solenoid switch throws "off."

The diagram of connections shows a slightly different type of solenoid switch from that illustrated; one in which a single solenoid accomplishes the same result. This is shown thus, as it is much easier to trace out the path of current, in illustrating the operation of the system.

The relative advantages of the series-parallel system over the rheostat control with one commutator is readily apparent by an inspection of Fig. 10, in which the curve shows the comparison between the two systems, when operating a Hoe Quadruple Press. It will be seen that the current required to exert the maximum torque when starting the press from rest is somewhat

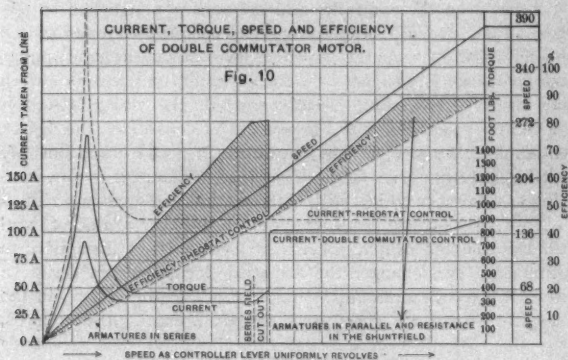
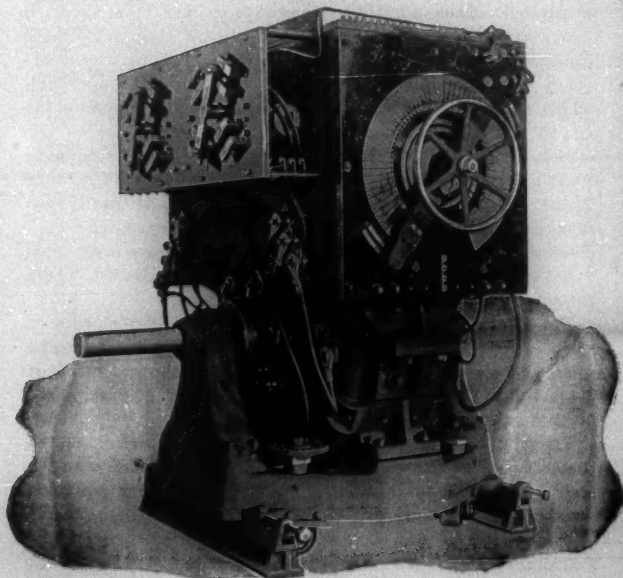


FIG 10



less than the current required for the same operation by a single compound wound motor with rheostat control. Also the efficiency at all speeds is much better.

While the system was originally designed especially for operating Webb presses, it is equally well adapted to any service requiring heavy starting torque, a wide range of speed variation, ease of manipulation and high efficiency.



FIG. 12.



FIG. 13.

A portable motor for use in testing printing presses, is shown in Fig. 11. This gives a very good idea of what can be accomplished in this direction. The entire apparatus is mounted on the motor frame, and is quite easily moved to various departments.



V

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MULTIPLE UNIT, VOLTAGE SPEED CONTROL FOR TRUNK LINE SERVICE.

BY H. WARD LEONARD.

A description of a single phase, high tension, alternating current system for operating trunk line railways. Conversion takes place on each locomotive and substations are eliminated. Illustrated.

In February, 1894, I read a paper before this INSTITUTE describing a system which I considered applicable to the operation of a trunk line electric railway. The essential features of this system were:

1st. The generation and transmission of a high tension single phase alternating current, the power houses being placed as far apart as the insulation of an alternating current transmission would permit.

2d. The entire elimination of sub-stations.

3d. A transformation of the energy upon the locomotive so as to secure a voltage speed control for the electric motors, thereby obtaining smooth acceleration and efficient control of the locomotive at any desired speed and in either direction.

At that time there were no engineers, so far as I know, who agreed with me that these features were essential for the operation of a trunk line railway by electric motors.

In the recent past, however, many prominent engineers both abroad and in this country have declared themselves in favor of these essential features, and I therefore feel warranted in describing an improvement upon the system I originally proposed, by which I can secure the important and now well understood advantages of a multiple control of any desired number of locomotive units.

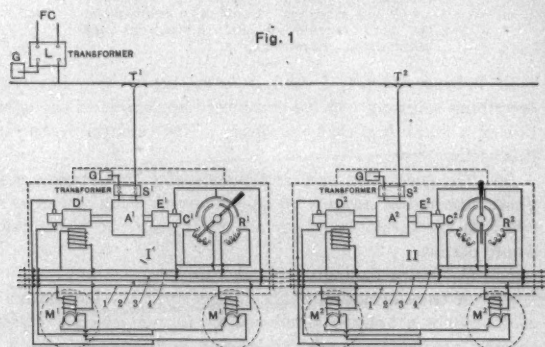
Fig. 1 illustrates diagrammatically one form of my multiple unit, voltage speed control as applied to two locomotive units for trunk line service.

The current is generated in the form of a single-phase alternat-

ing current at as high an e.m.f. as is practicable to-day, say 20,000 volts. A moving contact leads the single phase alternating current upon the locomotive. If desired, static transformers can be placed at suitable points along the line of the railway which will reduce the initial e.m.f. to any desired lower e.m.f. upon the contact conductor.

In many instances it may be desirable to place upon the locomotive a transformer s' for reducing the tension of the alternating current led to the synchronous motor A^1 .

A single phase synchronous motor on the locomotive receives this alternating current and is driven by it continuously at a practically constant speed; the current after passing through the motor, being led to ground through a moving contact. This



single phase motor A^1 drives continually a small exciter E^1 and also a large continuous current dynamo D^1 whose field is separately excited by the exciter E^1 and has in its field circuit a reversing field rheostat R^1 . The armatures of the propelling motors are connected in multiple directly across the terminals of the armature of the dynamo D^1 . The field magnets of the propelling motors M^1 are separately and constantly excited by the exciter E^1 .

By manipulating the reversing field rheostat R^1 , the current through the armatures of the motors M^1 necessary to obtain the required tractive effort, can be obtained at any desired voltage from the lowest voltage to the full speed voltage, and in either direction.

A perfectly smooth and rapid acceleration can thus be obtained with minimum energy from the source of supply.

The simultaneous multiple control of the several locomotive units is obtained by means of the four small wires 1, 2, 3, 4, which are lead along the train.

In Fig. 1 the operator is supposed to be upon the locomotive I. The exciter E^1 , which is producing a constant e.m.f., has its terminals connected to the wires 1 and 2. Across these wires 1 and 2 are connected the field windings of all of the propelling motors on the two locomotives, so that they are all constantly and fully excited.

The wires 3 and 4 are also supplied by a current from the exciter E^1 , but the reversing field rheostat r^1 is in the path of this current. The fields of the two dynamos D^1 and D^2 are connected in multiple across these wires 3 and 4 which extend along the train.

It will be evident that by manipulating the reversing field rheostat r the operator can vary, simultaneously and similarly, the field exciting currents supplied to D^1 and D^2 and that therefore he can cause the voltage of these two dynamos to vary in exact unison from 0 to the maximum voltage in either sense. Thus, the operator can cause the two locomotives to start, accelerate, run at full speed, retard, and reverse in perfect unison, always dividing the load perfectly under these various conditions.

By placing the controller R^1 in its open position and going to the other locomotives, the operator can similarly control the two locomotives simultaneously by means of the controller R^2 .

By the use of this system I expect to be able to secure the following advantageous features:

1st. The haulage over existing roadbeds, grades, bridges, etc., of very much heavier trains than can be hauled by any steam locomotive.

2d. A material reduction in the cost of maintenance of the locomotives as compared with steam locomotives.

3d. A material saving in the maintenance of the road bed because of the absence of hammer blow, shouldering, rocking and skidding.

4th. A material increase in the weight of the train which could be hauled around a certain curve by a locomotive having a certain weight on drivers.

5th. A material increase in the load which could be started

upon a certain grade by a locomotive having a certain weight on drivers.

6th. A material reduction in the dead load necessarily hauled by a steam locomotive, represented by the part of the steam locomotive and tender not on drivers.

7th. A very large increase in the number of trains of given weight and speed which could be operated from a given power house compared with the series parallel or cascade systems. Or, to state this another way: a very much higher rate of acceleration with the same maximum output from the power house, the same conductors, the same weight per train and the same watt hours per ton mile, than is possible with the series, parallel or cascade systems.

8th. As each locomotive unit can be equipped with any desired number of driving axles and any desired number of locomotives can be operated under multiple control, the amount of power which can be applied to a single train and controlled by a single operator is practically unlimited.

9th. Fifty per cent. of the energy now wasted on friction brakes can be saved in the form of useful electrical energy restored to the system.

10th. The first cost of equipment will be very much less than that of any system, for equivalent service, which involves the use of sub-stations.

11th. The cost of haulage per ton mile will be greatly reduced as compared with steam locomotives, especially because of the large increase in the weight of the train which can be hauled.

12th. Difficulties due to electrolysis would be reduced to a minimum.

CONTINUOUS CURRENT MOTORS FOR MACHINE TOOLS.

BY F. O. BLACKWELL.

A description of the characteristics of the different classes of metal working tools, of the requirements of motors for operating them, of the conditions limiting the range of speed variation and some of the methods of obtaining it with continuous current motors.

The application of electric motors to machine tools is a subject requiring a great deal of study in order to obtain the best results, each case having to be treated as an individual one. In most shops it might be economical to have the bulk of the machines driven by individual motors, while in others group driving would be better.

Planers, slotters, milling cutters and many other tools need only a slight variation in speed, as the relation between the tool and its work is always the same, variation in speed only being required for different classes of work, that is, for hard or soft metal or for a roughing or a finishing cut. Such work does not require more than a 2 to 1 variation, while, on the other hand, lathes, boring mills and other rotating tools may require an 8 or 10 or even 40 to 1 variation, necessitated by the varying relation between the tool and different diameters of the work. For instance, take a lathe in which is being turned a shaft 6" in diameter, to obtain a cutting speed of 50 r.p.m., it will require approximately 32 r.p.m. of the main spindle; while if the flange of a 48" wheel was being turned, it would require only 4 r.p.m. of the spindle to obtain the same cutting speed. It can therefore be seen that such tools of necessity require a large amount of speed variation to obtain the best results.

There are a number of methods in use for attaining this variable speed by means of the electric drive, the more common being rheostatic, field, and multiple voltage control.

Either the rheostatic or the multiple voltage method combined with the field control of the motor makes a very flexible system. For example, a motor having 100 per cent. field control used on the three-wire system will give a speed variation of 4 to 1, or a motor having 35 per cent. field control used on a four-wire system with potentials of 60, 80, 110, 140, 190 and 250 volts, will give a speed variation of approximately 6 to 1, or having potentials of 40, 80, 130, 170, 210 and 250 on 8 to 1 speed variations, the gaps in speed between the various potentials being filled in by field control of the motor.

Having at hand an easy method of control, the question arises,—how far can we efficiently apply this method to advantage? It has been demonstrated many times that it takes practically a constant horse-power to remove a given amount of metal per minute, irrespective of the rotative speed of the tool. Therefore, the main spindle of a lathe taking a $\frac{3}{8}$ " cut on a 6" steel shaft with a feed of $\frac{1}{8}$ " and a cutting speed of 50 r.p.m. makes 32 r.p.m. and takes a certain horse-power to drive which we will assume to be 15 h.p., and the motor will be working on its highest potential or 250 volts. Now, if we are using the multi-voltage system with the last-named potentials above, and should put a 48" wheel in this same lathe and turn up its rim with the same cut, feed and cutting speed, the main spindle would run at about 4 r.p.m., or one-eighth of the previous speed, but still requires 15 h.p. to drive. With this condition the driving motor would have to run on its lowest potential or 40 volts, and would be consuming fully six times the amount of current it did previously. It is therefore seen that a motor to be used on the multi-voltage system will have to be sufficiently large to carry its maximum horse-power at the minimum potential, or in other words, at say 40 volts on a 250 volt system, the motor will have to be six times too large when working on its maximum potential. For this reason I feel that we must keep the lowest potential employed as high as possible in order that the size and cost of the motor may be within reasonable limits. A potential of 40 or 60 volts, requires such large conductors if they are laid out for a small drop that their cost is prohibitive in a plant of any size. If a large drop is used, the motor falls off in speed under load and its speed regulation under changes of load is little better than with the rheostatic control.

With the three-wire system and a 100 per cent. variation in the motor speed by field control, we can obtain a 4 to 1 total variation which, for general machine shop work, is sufficient to cover a single operation on a given tool. The total range, however, on a tool can be increased greatly by having a few gear changes. For example, on a back-geared lathe with a gear ratio of 4 to 1 a total variation of 16 to 1 can be obtained. In the same manner on a double-geared lathe a variation of 64 to 1 might be obtained.

The reduction effected by different sets of back gears on machine tools will be found to vary from 4 to 1 to 6 to 1. All tools can be arranged with 4 to 1 changes between back gears without any difficulty. In many cases a single back gear is sufficient for a tool. By putting a magnetic clutch on this back gear and making the electrical connections in the controller, it is possible to get a 6 to 1 variation electrically and without increasing the cost of the motor more than would be required for a 4 to 1 variation.

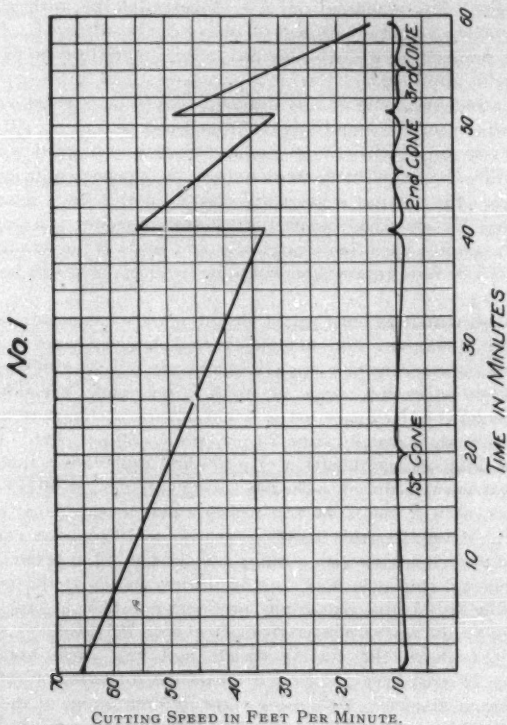
Where machines must run at various speeds, the usual practice has been to employ step cone pulleys and changeable gears. The speeds obtained in this way, however, are few in number, and therefore as a wide range of speed is necessary, the different speeds must be far apart. The minimum speed change of lathes, for instance, is usually from 25 per cent. to 50 per cent. If the speed with one combination of gears and pulleys is a little too high, it can be reduced to the next lower speed (25 to 50 per cent. lower), with a loss of output nearly equal to the reduction in speed. If, on the other hand, power is furnished by a variable speed electric motor with a range sufficient to fill in between the mechanical steps, the tool may be driven always at the highest possible speed and maximum production. This is best illustrated by the curves plotted from a test on a 72" lathe.

Fig. 1 shows the cutting speeds and the time taken to face a 72" cast iron disc from a maximum diameter of 72" to a minimum diameter of 6", using three different steps of the cone pulley, the time for shifting the belt from one cone to the other not being included. The cone pulleys on a mechanically driven tool do not permit the tool to start at the maximum cutting speed, and in this case the mechanic, having no guide but his eyes, did not change the speed on the cone pulley as soon as desirable for greatest production.

Fig. 2 shows a test on a similar lathe but driven by a

motor. With the electrically driven tool the cut begins and ends at the maximum cutting speed that the work permits.

As will be seen from the curves, a belt driven lathe required 59 minutes to complete the cut, while the motor driven lathe did the same work in 31 minutes. The electrically driven tool, therefore,



did the work in 53 per cent. of the time, or putting it in another way the belt-driven tool required 90 per cent. more time to do the same work.

With electrical control a man can keep his hand on the controller and his eye on the tool, increasing the speed from time to time. Being limited only by the temperature of the tool, it has

been found that much higher cutting speeds are unconsciously attained with a motor-driven tool than would be thought possible were any fixed rule followed. It is therefore apparent that this increased production in many cases is so great as to fully justify the installation of an electric system, even if there were no other advantages to be secured.

The costs of motors vary with their size and (for a given horse-power) nearly in proportion to the variation in speed which can be obtained from them. The approximate relative sizes of the motors expressed in the horse-power capacity at which they could be rated at the maximum potential are about:

SYSTEM.	SPEED VARIATION.	RATIO OF MAXIMUM H.P.
Two-wire	50-100	100
Three-wire	25-100	200
Four-wire	16-100	400
Four-wire	12-100	600

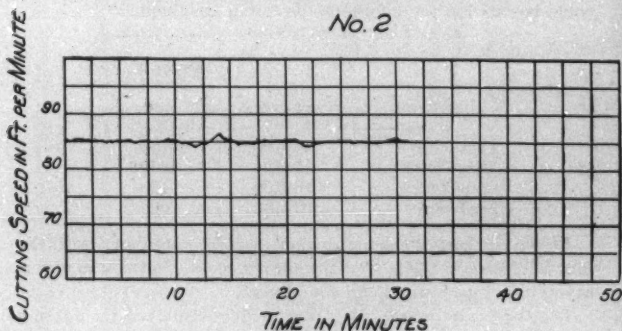
Beside the cost of the motor there is to be considered with the four-wire system the cost of the supply plant, that is, the generators, motor-generators and conductors.

The three-wire system is now generally employed for lighting and requires no special appliances. Nearly all central power stations distribute their current for lighting and power on the three-wire system so that it can generally be obtained and the erection of a special power plant avoided. The three-wire system can be always arranged so that the motors running at one-half potential will be equally divided between the two sides of the system, which will therefore be in balance, and as there is but little or no current flowing in the neutral wire, it can be of nominal size. The three-wire system does not necessarily require two generators or a balancer set, an alternating neutral with collector rings on the generator being extensively employed.

The four-wire system requires a three commutator motor generator set which must have sufficient current capacity at the lowest potential to run all the motors that could ever be in service at one time at their full horse-power at that potential. The motor generator set and the heavy wiring for the low potentials of the four-wire system will much increase the cost, exclusive of motors as compared with a three-wire system. If the motors are

made of sufficient capacity to run the rotary tools at reduced speed and the motor generator set and distribution cables are made of proper size to take care of the unbalanced load, the four-wire system will altogether cost several times as much as the three-wire system.

In conclusion, I would say that in my opinion it will generally be found best to use motors with field control, allowing a total speed variation of 2 to 1 with the two-wire system or 4 to 1 with the three-wire system, believing that the four-wire system is too expensive for general application if the plants employing it are



properly designed and equipped with large enough electrical apparatus.

For reciprocating tools a two-wire system will meet all requirements, and there are very few cases with rotating tools where it is not better to vary mechanically the speed for greater than 4 to 1 changes in speed.

The most important consideration in the electric driving of machine tools is to make the control of the tool as convenient as possible and arrange the system so as to permit small changes in speed, and consequently be able always to drive the tool at its highest possible speed and greatest output.

After reading the paper, Mr. Blackwell said: I have a diagram of an actual test on two lathes, one with the electric motor drive and the other driven by cone pulleys and belts. The diagram on the left shows the cutting speed and time required to face a seventy-two inch cast iron disk, starting from the outside and working towards the centre. The workman started the machine as near the maximum cutting speed as possible, but it was not the

maximum speed he could get. In this case he started at 65 feet a minute, and worked down to 30, which he thought was the right point to change, then he changed to the next cone of the pulley. The actual time required to finish that face plate was about 60 minutes. On the electric tool he had a variable field control and as he had the controller in his hand, he could watch his tool all the time; and he tried to run as near as he could to the maximum, which was supposed to be about 100 feet per minute. As a matter of fact, he got rather low. He started on 85 feet per minute, the variations being only 4 or 5 per cent. The result was he kept cutting at 85 feet per minute throughout the run, and finished the entire cutting in 32 minutes, practically half the time he took with the cone pulleys; that is about the experience of nearly every one who has had anything to do with electric driving of machine tools. The use of the electric drive nearly doubles the total output.

DISCUSSION.

PRESIDENT SCOTT:—We have had a meeting which is particularly interesting, because all except two papers have considered what is practically the same problem, the means of accomplishing the same end. We will have the discussion opened this evening by another gentleman who has given a great deal of attention to this same problem, Mr. Gano S. Dunn.

MR. DUNN:—The Company with which I am connected is at present engaged in litigation involving a number of the features presented this evening; and very greatly to my regret the attorneys of the company have requested that I do not take part in this discussion. However, as you have been so kind as to call upon me, I think I may with propriety refer to certain matters relating to the general design of electric motors.

Several of the authors describe systems in which a motor is expected to give a constant horse power over a speed range varied from 1 to 2, by means of field weakening. This means that if a motor is fully loaded at a given speed, it will be called upon to take the same current and deliver the same horse power at double the speed, and with a field weakened 50 per cent. My experience is that it will not do this satisfactorily unless it is a special motor. The question is particularly important in connection with the operation of machine tools, on the system described by Mr. Storer, since the motor might be used to drive a lathe, where heavy torques occur in the lower ranges of the speed, when the motor runs with a greatly weakened field on 110 volts. The motor, which he describes as a 5 h.p. motor, running normally at 375 r.p.m., might be called upon for that 5 h.p. at a speed nearly equal to 750 r.p.m., under a field weakened nearly 50 per cent. If the motor is designed to give proper commutation with normal field strength, then in my experience it will not give it with only half of that field strength. A motor designed with an abnormal and excessive field strength is, of course, susceptible of speed increase by a reduction of this excess, but such a motor is special and expensive.

If you submit a standard motor to a similar degree of field weakening, the commutation will be unsatisfactory. Unsatisfactory commutation does not always mean sparking. It means commutation that in the course of time destroys the commutator.

PRESIDENT SCOTT:—As I intimated in my opening remarks, we are quite fortunate in having the actual apparatus which is presented by different companies for this class of work, represented by representatives of the companies. While we regret that Mr. Dunn has found his limitations, for once at least, in discussing the merits of the direct current motor, still the reason is one which we must, of course, respect; and we must remember that although there are often limitations of this kind introduced, particularly with regard to new subjects, we ought to be glad to

hear as much as possible from our members upon important subjects, even though they must stop when the limit comes. We can hardly afford to decline to hear anything of a new subject simply because all cannot be told. Under such circumstances we would often have to wait until the subject became stale before we could learn anything about it. We will be glad to hear from Mr. H. E. Heath, of Windsor, Connecticut.

MR. HEATH:—I am obliged to you for calling on me, but I may say I have practically left this branch of the subject after having given it fifteen years' attention. I agree with Mr. Dunn in saying with the ordinary construction of the standard motor, if you propose to get a wide range of speed by variation of field, it will necessitate the use of a much larger motor. But that is not saying that a special construction of motors cannot be used, because I know, and perhaps a number of other gentlemen here know, that a form of motor can be made that will give us practically sparkless commutation over a fairly wide range, and still not be largely in excess, with regard to either cost or weight, of the standard motor. For reasons perhaps similar to those of Mr. Dunn, I do not care to say much more about this. I think that within a year or so he will be at liberty to say a good deal more than he can now.

PRESIDENT SCOTT:—Will Mr. S. T. Dodd of the Stanley Electric Manufacturing Company, favor us with some remarks?

MR. DODD:—It is so late I really do not feel I should take up any time in discussing this subject. I was interested in Mr. Leonard's article on the application of his multiple-unit voltage speed-control to railways systems. I would ask Mr. Leonard what facts he can give us in regard to the weight efficiency of such a locomotive as he describes. It will be impossible ever to apply such a system as he describes to single cars or small units, and the only field for such a locomotive will be for trunk line service. Now, let us consider a large locomotive like the B. & O. tunnel locomotive. The weight is 96 tons. I do not know exactly how much waste room or waste weight there is, but I do not think there is much of either. These locomotives are operated by a motor-generator booster set, which weighs 36 tons, and raises the voltage from 500 to 700. Suppose that these locomotives were equipped on Mr. Leonard's system and that each was furnished with a motor-generator, which instead of being a booster was capable of developing the whole current for the locomotive at full voltage, that is, had a capacity of about 750 k.w. Such a motor-generator would weigh at least 50 or 60 tons, making the total weight of the locomotive about 150 tons. Such a weight is not prohibitive, but it would seem to indicate that an electric locomotive equipped on Mr. Leonard's system would weigh a good deal more than a steam locomotive for doing the same work. On the contrary, we have been anticipating and prophesying that the electric locomotive of the future would increase rather than decrease the weight efficiency of our moving units.

PRESIDENT SCOTT:—A gentleman who has to do with motors at work is Mr. Arthur Williams, of the New York Edison Company. We would like to have Mr. Williams give us his experience in this matter, bearing on the general subject under discussion.

MR. WILLIAMS:—Our experience in applying motors directly to shop tools has been very much of the order described by Mr. Lozier, but I think, Mr. President, he takes almost too low an average for the demand upon the supplying service. If I understand his figures, this average is about 10 per cent. In my experience it is more nearly 25 per cent. to 30 per cent.

There is also to be remembered in using for regulation the neutral wire of the three-wire distributing system, that large power loads are apt to unbalance the system and lessen the quality of the service. That has to be very carefully considered. In New York are certain points where in single units, 120 volt motors are as large as 50 h.p., even larger, but there are few sections of the system that can withstand so much unbalancing.

It seems to me that these strides in the equipment of factories with individual motors are in the right direction, and quite in line with what was predicted of the future at a meeting of the INSTITUTE some three years ago. The first cost of installing individual motors is much greater, but the difference is partly offset by the saving in shafting and belting. As soon as the two methods are compared, one using belts and shafting and the other individual motors, there is no question whatever as to the inferences to be drawn in favor of the individual motors. Work can be turned out at sometimes 100 per cent. greater speed, and even higher percentages of increase, and there is great economy in power. I think it is not improper to say that the average loss of power in machine shops where belting and shafting are used, is 50 per cent. of the total power consumed; by using individual motors a very large part of this loss, not substantially all, can be saved and such savings aggregate a very large sum annually. The cost of power service, using individual motors, with current at 6 or 7 cents a kilowatt hour at the meter, is from \$20 to \$30 a year per h.p. These figures are based on the capacity of the plant, and are actual in general machine shop work, and in several of the largest printing establishments.

PRESIDENT SCOTT:—We have a gentleman with us this evening, who joined the INSTITUTE in 1888, and he is therefore one of the oldest members, but this is, I believe, the first meeting of the INSTITUTE which he has attended. He is a man who has had a great deal to do with the subject now in hand, as he has been superintendent, and is now manager, of one of the largest machine shops of the country, in which electric drive is employed, and he may have a few words to say in regard to this subject. I refer to Mr. Philip Lange of Pittsburg.

MR. LANGE:—I do not believe that I can add anything to what has been said about controlling variable speed direct cur-

rent motors. All of the machinery of the establishment with which I am connected is driven by constant speed two-phase motors, and we have been compelled to accomplish with alternating current motors those results which were pointed out as having been accomplished by direct current motors. Most of our tools are grouped, and we are using the individual motor drive only for some large tools, and there we accomplish the variations in speed by some mechanical devices such as variable speed counter shafts, nests of gears, etc. I fully agree with Mr. Blackwell's statement that it is very important to provide means to vary quickly the speed of tools in order to get results such as he described; in one instance, reducing the time required for machining by one-half by the use of a proper speed controlling device. We have accomplished similar results by mechanical speed varying devices, as the alternating current motor is not very well suited for speed adjustment.

If any of the gentlemen present wish to ask any questions as to how we accomplish some of the results we have attained by means of alternating current motors, I am ready to answer, but I cannot add anything to what has been said regarding the performance of direct current motors.

MR. CHARLES DAY:—I have been very much interested in the papers of the evening, which have described in such detail the various systems of obtaining variable speed by means of the direct current motor, but I have not as yet heard a satisfactory answer to the question asked by the President when opening this discussion, a question of utmost importance to all manufacturers contemplating improvements or extensions to their machine shops;—does it pay to put individual motors on machine tools, and if so, does it pay to go to the additional expense of obtaining variable speed?

Mr. Lozier touched on this subject in the latter part of his paper, where he referred to the radical changes that shop management and practice have undergone during the last few years.

Over seven years ago Mr. Horace L. Arnold wrote a splendid article on this subject entitled "Production to the Power Limit," stating in the most forcible manner the principles underlying economic production. It seems to me that any one who is contemplating the advisability of driving machine tools with individual motors, could not do better than read this short article and then endeavor to follow up this line of thought by making a most thorough study of the requirements of each particular machine.

During the past three years few subjects have received more attention in the technical papers and engineering organizations than the use of the motor as a means of driving machine tools, but so far the discussions have usually dealt with details of motor design and operation, or the advantages derived from electrical driving only, considered in the most general way. It is time that we consider this subject from a broader standpoint,

giving the motor the position that it rightly holds, but not losing sight of other factors, the development of which are essential to the efficient operation of the scheme.

If a machine shop is to be run in the same way after the introduction of a costly system of motor driving as before such an expenditure, interest and depreciation will not be made on the investment. On the other hand, the shop superintendent who is thoroughly alive to the possibilities in machine shop work may find in the motor a solution to certain details which make possible the highly efficient results he is aiming for.

Ease of handling and close speed regulation, the principal advantages claimed for the variable speed motor, are terms that can only be used in a relative sense; and the saving effected by bettering these conditions will only justify a certain expenditure, therefore the cost of different methods of arriving at the result should be most carefully considered.

One of the speakers said in the discussion that the problem of machine tool operation had been turned over to the electrical engineer, the mechanical engineer failing to accomplish the desired result.

I feel that it is a great mistake to intimate that a field of as broad a character as the one we are discussing should be entirely in the hands of any one division of engineers, their combined efforts being necessary if the desired result is to be arrived at in the least time. There is no definite amount of data that can be placed in the hands of the electrical engineer to form a basis for his work, but he must personally familiarize himself with every detail of shop equipment, methods and requirements before the need of certain improvements is felt with sufficient force to call forth his best efforts in design and construction. The impressions and convictions that one arrives at after earnest study of present conditions and possibilities in the machine shop lose their force when repeated to another party, and the relative importance of all the details that make up the general scheme is lost entirely.

Such details as the total range in motor speeds, and the number of running points required, differ in each of the systems described this evening, and if we wish to decide which one to adopt we must know the character of the metal we are machining, the cuts we can remove and the speed made possible by the tool steel used and the facilities for driving the work. The means provided for determining the cutting speed is another important factor, as it is the ability to use the apparatus to its full efficiency under working conditions that determines its real value. I have seen over and over again controllers designed to give a speed regulation of 5 per cent. introduced into machine shops where the operators had no facilities for judging the correct cutting speed closer than 30 to 40 per cent., the advantages of the much-talked-of close speed regulation being entirely lost.

Mr Blackwell stated that 4 to 1 was sufficient range in speed for

efficiently machining any *given piece of work*, and dwelt at some length on this particular case, showing charts of the savings effected by the use of a variable speed motor. In shops doing a general line of work, it is very seldom that work turns up where the tool cuts from the outside to the center, and this problem is never the deciding factor in the range required. Speed control is obtained in nearly every case by a combination of mechanical and electrical means, the motor range and gear ratios depending upon the machine, and the average variation in diameters and kind of material handled.

When attaching motors to old tools, such as lathes and drill presses we must, as far as possible, adapt our speed range to the present gear ratios, in some cases by introducing additional gears, and in others without change to the machine. We have found that the gear ratios vary from 3 to 1 up to 15 to 1, depending on the size and character of the machine.

We have frequently endeavored by careful figuring to show just what saving would be effected by replacing the belt and step cone by a variable speed multi-voltage system, assuming in each case that the equipment was driven to its full capacity.

Taking into account all the limitations arising from variations in material, and so on, we have found it hard to show by such comparison a saving greatly in excess of the interest and depreciation on the investment. It is, however, the indirect savings that make the motor of such value as a method of operating machine tools. The power limit on most of the standard machines is absurdly low when we consider the high cutting speed that the modern air hardening steels permit of. On large machines, such as boring and turning mills doing general work, it is impossible to have the machinist shift his belt as often as he should, as by so doing he would be physically worn out at the end of each day, or if such a condition can be arrived at it would only last a short time, the workman soon relaxing his efforts until the old conditions exist again. The motor with its great facility of control removes all these difficulties, and but small incentive is necessary to assure the continued efficient operation of the plant.

We must ever bear in mind, while considering machine tool driving, that it is inconsistent to spend all our energy to develop one detail while other equally important factors are ignored. The feed mechanism on a lathe, for example, is too often neglected and so it is with many other details.

I want to call attention before closing my remarks to the erroneous impression usually conveyed when citing as a *characteristic example* the time saved on a given job; such data has no real value unless we know just how long the tool runs under cut, the hours it is working each year, the wages of the operator and many other details that it is impossible to carry in one's head.

At the works of our clients the Link Belt Engineering Company Nicetown, Pa., we have obtained data extending over four years from which we can figure the pound price of their product.

After taking into account every factor which might in any way affect the result and deducting 10 per cent. which was given the workmen in changing from a 10 to a 9-hour day, we can show a clear saving of 30 per cent. on the entire labor bill. This is due to better methods, tools, and tool steel, and better methods of driving the machines; and the saving is largely in excess of the interest and depreciation on the entire expenditure necessary to effect it.

It seems to me that if shop managers who have installed the motor as a means of driving individual machines, would endeavor to get data of this kind, the advantages which can be derived from such an installation would be made evident and aid greatly in the general adoption of such systems.

PRESIDENT SCOTT:—Mr. Day's remarks seem to me to be an elaboration of the first sentence which I used in introducing the papers on this subject, to the effect that applications of electricity lead to the revolution of old methods as well as to the evolution of new ones. What he says reminds me of the remark which I heard the superintendent of a factory which is at present enlarging its capacity, make within the past week. He said that of the new machines which were being ordered, a very large number were ordered specially, at an excess cost of 50 per cent., simply in order that they may be mechanically strengthened so as to stand the high speeds at which it is expected to operate them.

If there is no one else who wishes to add to the discussion we will close by calling on those who have read papers. I will call upon the gentlemen in the inverse order.

MR. LOZIER:—One point that has been referred to by Mr. Williams is the question of distributing motors over a system operated by three-wires. If you divide the number of motors by 6 you get a smaller quantity than if you divide by 2; in other words, if you are using a three-wire system, with only two voltages, and these voltages cannot be combined to give three voltages, the motors will bunch up on one voltage much more than if you distribute them among the six. We have not found that the balancer is at all disturbed by the motors running at any one speed bunching up on one voltage.

I would like to go on record to say that it is up to the tool builder to give us tools that will be strong enough. I say this in order to help the general cause, because at present we are limited in the output of the tools, because they are not strong enough.

MR. N. W. STORER:—I believe the only question raised in regard to my paper was brought up by Mr. Dunn in reference to the commutation of the motors with a weakened field. He claims that it is impossible for a standard motor, properly designed, to commutate with a field one-half its normal strength. I am entirely unable to agree with Mr. Dunn. Referring to the point I sought to bring out in my paper, I gave as an example a 10 h.p. 220 volt low speed motor. Running at half the voltage and

half the output, the current in the armature would be the same as at the normal rating of 10 h.p. It ought to be well understood that a motor running at a lower voltage than its normal will commute through a greater range of load with a weak field. I believe Mr. Dunn will agree with that. If you consider the Ward Leonard system, which is quite well-known, you will find a generator which commutates from possibly one-fifth or one-sixth of its normal voltage up to its maximum voltage with any load within its range. I have not heard that point questioned to-night. It is possible that that is quite a special generator, but I do not think you will find it so. A low voltage gives greater possibility for the motor, and the standard motor on a low voltage, the motor being properly designed, ought to be able to commute with an extremely weak field. I have run these motors to the point where the field was only one-half the strength of the armature, and they were perfectly stable. It is well known that in designing and in building motors of different sizes, standard parts may be variously combined for specific purposes, so that it is very simple in some combinations to get better proportions than would be made if one were to design especially for some exact condition. It is so with a 220-volt motor. I do not think there is any difficulty in reaching the condition which I outlined in my paper. Dr. Dunn made the point that this would be a special motor. It may be a specially good motor. It is a standard make of motor, however. Will a motor used on the multi-voltage system be a standard motor? The example which I gave you called for a 20 h.p. motor, rated normally at 220 volts, and 1500 r.p.m., and it met the conditions which I gave for a 5 h.p. variable speed motor. Prominent manufacturers do not make 20 h.p. motors, normally running at 1500 r.p.m. I do not think there is anything in the market which calls for such a motor, with a range of speed of only 4 to 1. If you have 6 to 1, unless you get 200 revolutions or thereabouts for minimum speed, which makes an enormous motor, you will have a normal speed of the motor of possibly 2000 or 2500 revolutions. Such a motor is not a standard motor. That is a point you must consider. You might take a 110 volt motor, and in that case you would have to run it at double its normal voltage, and it would have to be an especially good 110 volt motor.

These are some of the points which must be considered. The three-wire system requires a somewhat different type of motor; it is primarily a good commutating motor, and I believe there are a half dozen different firms in the country which are putting out such a motor. A multi-voltage system requires a special motor, or a motor designed for a speed out of the range of what is ordinarily required. It must be designed with the idea of using it for the multi-voltage system. Mr. Heath, I believe, agreed very nearly with me in that respect. He claimed that while the standard motor ordinarily would not do that, it was usual to make a motor which would do it with practically no increase in cost. That is what should be done.

In regard to Mr. Leonard's paper, Mr. Dodd struck the nail on the head. Such a system, I believe, will increase the weight of the locomotive far beyond what is ordinarily required for the power of the locomotive. I believe if you take a large locomotive you will have scarcely any excessive weight necessary, if you consider the motors and the necessary parts of that locomotive. This is my experience in figuring on railway work, and I believe if you add to these a motor-generator outfit you will have a locomotive which is 50 per cent. heavier than it should be.

MR. H. WARD LEONARD:—Before touching upon the question of the weight of the locomotive, I would like to make a slight response to the point that the multi-voltage system requires something special in the shape of a motor. I think if there is any system that requires nothing more than the simplest standard form of motor, it is that system. The first time the multi-voltage system was tested was when I presented it to William Sellers & Co. in 1891, and the simple standard shunt motor in use at that time was tested over the entire range of the various motors touched on this evening, with perfectly satisfactory results in every way.

As to the locomotive question, I will not spend any time on the B. & O. locomotive, which, although historically interesting, we all know is absolutely uncommercial as a possibility in the direction of freight haulage on trunk line service. I think it is likely there is not much room on that particular locomotive for a motor-generator, as I know that after the locomotive had been put in service, the company which built it, carefully considered whether they could put a motor-generator on it, and apparently they did not find room for it. As to the question of the effect of the weight of the motor-generator in locomotive practice, I beg to point out that the heaviest locomotives which have been made in recent years, such as the decapod locomotives, have only about 50 per cent. of their entire weight on drivers (including tender). When the cylinder capacity was then increased in an endeavor to secure better power results and to secure larger tractive effects, the next difficulty that was met was that they would too readily skid the wheels as the weight on the drivers was not sufficient to take care of the power produced, and various complicated devices have been invented and used in recent years to shift a part of the weight of the locomotive when starting the load, in an endeavor to secure more weight on the drivers at that time. It is, therefore, not only important, but really essential that you get more weight upon the drivers of any locomotive such as I am considering than the weight of the motors alone would give you. Furthermore, admitting for the sake of argument that the point is well taken that the dead weight hauled is increased by the motor-generator, I still wish to point out that the weight of such a motor-generator would not compare with the weight of the propelling motor, nor

with the weight of a motor-generator, such as is put in a sub-station. Such a motor-generator as would be employed on a locomotive would be comparable with generators that are driven by steam turbines, as to size and weight, and if the gentlemen who have spoken on this subject are interested in following the matter further they will find quite detailed figures as to the weight of the motor-generator relative to the total weight of the locomotive in a paper read before the Zurich Electrical Society by Mr. Huber, last spring, describing locomotives of the Oerlikon Company, which are being built on my system, and which will go into commercial use on a government railway in the next few months. *Still, however, going back to the matter of the weight, I wish to point out that if the present type of steam locomotive, having 50 per cent. of its weight on drivers, could be so made as to utilize double the horse power it now has, even though only 50 per cent. were on drivers (the remaining 50 per cent. of dead weight being more than equivalent to having to haul the motor-generator), the effect of such a locomotive as that would be enormous in the economies it would accomplish in the haulage of freight at the present day. There is scarcely a railroad in the United States that is not struggling with the problem of hauling its freight and what is wanted is locomotives which will haul twice as many tons as are now hauled; and even though it be a fact that in my system a few more tons are placed on the locomotive—50 or 60 tons or any such figure—when compared to the entire weight of a 3000 ton train, the haulage of this slight additional weight becomes entirely insignificant.

MR. DOWIE:—In connection with Mr. Leonard's paper regarding speed control of individual motors on locomotives, it may be interesting to compare the well-known Ward Leonard system of controlling direct current motors with some slight modifications of this system. The names given are sufficiently well known not to require any detailed description of the apparatus employed:

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Ward Leonard	100	148	123	371	271
Boost & Retard.....	100	74	61½	235½	135½
Teaser, Boost & Retard	100	49	42	192	92
Equalizer, Teaser, Boost & Retard	100	21	18	139	39

Column No. 1 gives capacity of working motor.

" No. 2 gives capacity of generator of motor dynamo, based on 90 per cent. efficiency and 33½ per cent. allowance for weakening of field.

" No. 3 gives capacity of motor of motor dynamo, assuming 90 per cent. efficiency.

Column No. 4 gives total capacity of machines required.

" No. 5 gives the excess capacity above that of the working motor.

It will of course be understood that the controlling apparatus becomes more complicated as the systems progress, but suitable controllers could be designed to give a full range of speed from zero to maximum in either direction.

In connection with the remarks made on multiple voltage systems, it is pertinent to call attention to the desirability of confining the range of voltage to as small limits as practicable. Where a wide range in voltage is used an excessively large motor must be employed, the wiring of the whole system must be heavy, especially the wiring of the small branch circuits and of the individual motors,—the use of circuit breakers on the individual motors is impracticable, because the size of balancing transformers becomes excessively large and the cost of installation is excessive.

If we can obtain a suitable direct current motor which will give a range in speed on constant voltage of about 3 to 1—and such a motor is entirely possible—then by the use of suitable changes of gearing we can obtain as wide a range of speed as is usually desirable. We avoid the complication of multiple voltage wiring, of special controllers, and the constant loss of the balancing transformer.

In order to obtain a very wide range of speed it is necessary to use changes of gearing; the question, therefore, to be determined is, how far shall the electrical variation be carried before the mechanical changes are introduced?

In designing shop equipments, not only must the best methods of obtaining variable speed be considered, but also care must be taken to install apparatus large enough to handle the increased output which is sure to follow when a system has been installed which provides easy means of adjusting the speeds of the tool.

MR. COHO:—As my paper provoked no discussion, I must either take it for granted that the gentlemen agree with me, or that they did not consider the paper worthy of comment.

With reference to Mr. Leonard's remarks, it seems to me that before the greatly increased speeds which we can obtain by means of electric locomotives and various forms of speed control, can be of any material benefit, it will be necessary for us to increase our track capacities enormously.

For the benefit of Mr. Dunn and Mr. Heath, I will say that if they will call at my office I will show them a motor which has a speed variation of 300 per cent. by means of field control, and which does not spark at the commutator.

PRESIDENT SCOTT:—If no one has anything further to add to the discussion, a motion to adjourn is in order.

[Adjourned.]

COMMUNICATION AFTER ADJOURNMENT BY GEO. A. DAMON.

The selection of the proper method of motor application and of speed control involves so many considerations that it seems to be a difficult matter to evolve what might be termed "standard practice" from the various methods offered. We are therefore fortunate in having the subject presented from different points of view and it is to be hoped that the discussion of these papers in the various INSTITUTE meetings will indicate the "tendency" of engineering practice along these lines.

There can be no doubt but that the individual motor is gaining favor as the advantages of its use become more generally understood and as investors begin to appreciate the dividend earning possibilities of an investment in electrical drive equipment. It is therefore possible for an engineer in planning a new shop to provide for a separate motor on each machine and it would be instructive to determine under what circumstances such a course is justifiable.

If the shop is to have an entirely new equipment of tools, then the use of a separate motor for each machine should be carefully considered. Nearly all the tool builders are re-designing their products so as to accommodate the individual motor and the results indicate that the more flexible connection of power and the wider range of speed control made possible by the motor drive has allowed for a great improvement in the design of the tool itself. With the higher cutting speeds made possible by the individual drive, with the deeper cuts allowed in new steel and other materials, it is not unreasonable to expect the new tool, which has been designed with these improved conditions in view, to have an output capacity at least 50 per cent. greater than a tool for the same class of work but of the former belt-driven type. Under these conditions, the individual motor appears to be good practice. But it more often happens that the shop tool equipment is to include a number of tools which have already been used in the old shop and which are poorly adapted to the direct application of individual motors. Take, for instance, a group of lathes driven by belts from speed cones. To put an individual motor on each lathe would require a multiple voltage or double commutator system of speed control, either of which would involve an investment in motors and controllers and wiring at least six times as large as the cost of one line shaft motor to drive the entire group and in addition to this, is the expense of special brackets and mechanical connections between the motors and the tools. Under these circumstances, it is problematical whether or not the extra investment in electrical equipment is to be justified. The "tendency" at present seems to be to arrange the old belt driven tools in groups, allowing a ten to twenty horse-power motor for each group.

If the shop is to run on a "piece work" "premium" or similar system of compensation for its mechanics, then the use of elabor-

ate systems of speed control for individual motors may be justified. If each operator has a constant incentive to keep the output of his machine up to its full rated capacity for a given grade of work—and it is possible to vary this output by changing the speed of the machine by easy steps through a wide range—then the results obtained by the most efficient operation of the tool at all times may make insignificant the question of the extra investment required to install the control system.

On the other hand, there are situations in which an easy method of controlling the speed may be a disadvantage. For a large printing establishment, it was found necessary to design a device to lock the speed controllers so that if the press was run at all it was operated at a given speed, which speed was determined by the foreman for each job. In this way, it was made impossible for the feeder to soldier on his work behind the bosses' back. This incident is intended to emphasize the idea that if full advantage is to be taken of refined methods of electrical control, the operators in charge should also be worked up to their highest efficiency.

The practice at the present seems to be to put all tools requiring 5 h.p. and over on the individual motor basis and group all the smaller tools. There is certainly a tendency toward equipping even smaller machines with separate motors, down perhaps to 3 h.p. and also a corresponding tendency to reduce the size of the shafting motors driving groups, with the idea of having, as far as possible, one standard size for shafting motors all through the plant.

MEETING OF THE PITTSBURG LOCAL SECTION OF THE AMERICAN
INSTITUTE OF ELECTRICAL ENGINEERS.

(Minutes of Meeting held at Electric Club, Pittsburg, Dec. 4, 1902)

The meeting was called to order by P. M. Lincoln, who read extracts from the President's introductory remarks at the New York meeting, November 21, 1902.

The papers presented at the New York meeting were then abstracted as follows:

N. W. Storer abstracted his own paper, "The Three Wire System in Variable Speed Motor Work," and F. O. Blackwell's paper, "Motors for Machine Tools."

H. P. Maxim abstracted paper by H. B. Coho, "The Storage Battery as a Factor in Speed Control."

W. A. Dick abstracted paper by Geo. W. Fowler, "A Series-Parallel System of Speed Control."

E. M. Tingley abstracted paper by H. Ward Leonard, "Multiple-Unit Voltage Speed Control for Trunk Line Service."

R. W. Stovel abstracted paper by R. T. Lozier, "The Operation of Machine Shops by Individual Electric Motors."

G. H. Gibson then gave a resumé of the New York discussions upon the above papers.

The discussion as to the advisability of supplying tools with individual variable speed motors was participated in by Messrs. Stovel, Storer, Dusinger, Dick, Lincoln, Campbell, Winslow, Tingley, Stevenson and Barr. In this discussion the fact was brought out that where individual motors have been installed, the testimony is universally in favor of the system. The advantage of the individual motor system over the group system is not so much a question of efficiency as of greater convenience and increase of shop output. Numerous cases were cited of plants that had been equipped with individual motor-driven tools where the output had been very considerably increased and the quality of the work improved.

The discussion of Mr. Leonard's paper was participated in by Messrs. Storer, Tingley and Barr. It was generally admitted that the smoothness of speed control obtained by this system was ideal, and that a single trolley was the most feasible method for conducting current to the car. It was, however, pointed out that a single phase motor is difficult to start and time is required to synchronize. It may be started by means of a storage battery or by a split phase starting motor. A change in line voltage, the jumping of the trolley, etc., is almost sure to throw the motor out of synchronism. The motors on the different cars of a certain section are in synchronism and therefore rigidly connected together. Should one motor get out of step the remaining motors on the section would also get out of step. The single-phase motor is more subject to "pumping" than the polyphase motor and in general it is much more difficult to operate and is more liable to trouble. The apparatus on the locomotive is very expensive, notwithstanding that it may be driven at high speed. On account of the heavy starting current demanded from the generator with low field charge, it is necessary to make the generator with large overload capacity.

A number of claims are made in Mr. Leonard's paper as to the advantages of his system. It was pointed out that the reason for these different claims was not clear from the paper; and exceptions were taken to many of them as follows.

Second Claim: "A material reduction in the cost of maintenance of locomotives as compared with steam locomotives."

It was pointed out that the depreciation of the direct current generator operated at very high speed would be large on account of the fact that it must deliver heavy starting currents at low voltage, which would make good commutating conditions extremely difficult to obtain.

Sixth Claim: "A material reduction in the dead load necessarily hauled by a steam locomotive, represented by the part of the steam locomotive and tender not on drivers."

It was pointed out that the weight of the electrical equipment of the locomotive would be extremely heavy and at least 50 per cent. greater than would be necessary to give the necessary tractive weight on the driving wheels.

Seventh Claim: "* * * a very much higher rate of accel-

eration with the same maximum output from the power house, the same conductors, the same weight per train and the same watt-hours per ton mile, than is possible with the series-parallel or cascade systems."

Exception was taken to this claim on the ground that even if the claim is true on a trunk line railway, the gain of acceleration is of no material importance.

Ninth Claim: "Fifty per cent. of the energy now wasted on friction brakes can be saved in the form of useful electrical energy restored to the system."

Regarding this claim, it was thought that while it was possible that 50 per cent. of the energy expended in braking might be returned to the system under certain favorable conditions, it would ordinarily be very much less than 50 per cent., and for trunk line service the amount of power saved by this feature would be negligible.

Tenth Claim: "The first cost of equipment will be very much less than that of any system for equivalent service which involves the use of sub-stations."

The first cost of the equipment will depend upon the number of locomotives employed. If the number is large, the first cost will probably exceed that of a system involving sub-stations, as the cost of the locomotive equipment will be very high and the cost of motors will be higher than the cost of series motors for the same service.

In the discussion of Mr. Coho's paper, Mr. Maxim was asked for information regarding the operation of a series of storage cells when the load is drawn from only a portion of the cells in the series. Mr. Maxim stated that the cells from which the load is taken would be discharged more than the remaining cells, but that this difference was ordinarily not serious and when the batteries were again charged, the cells from which the load had not been taken would be slightly overcharged.

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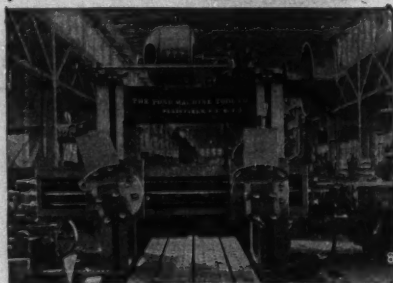
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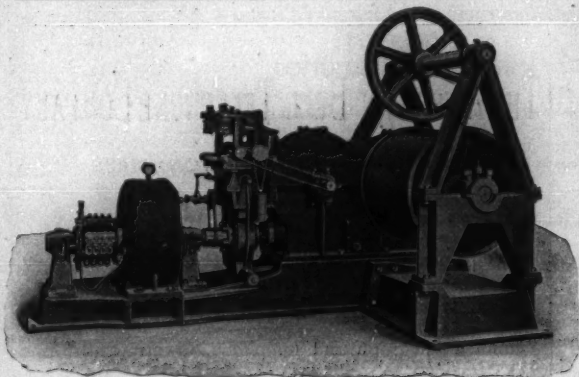
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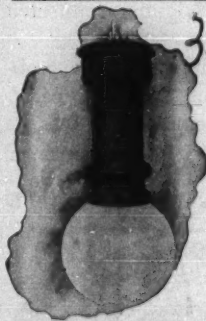
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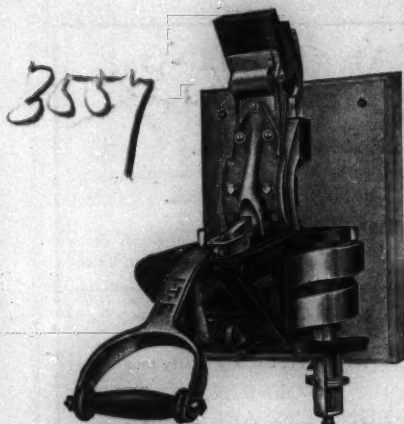
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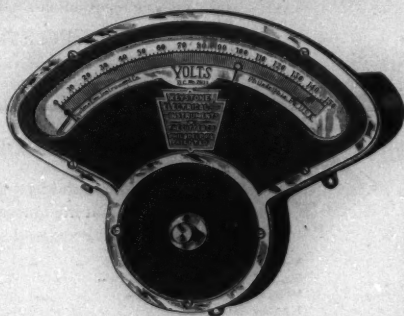
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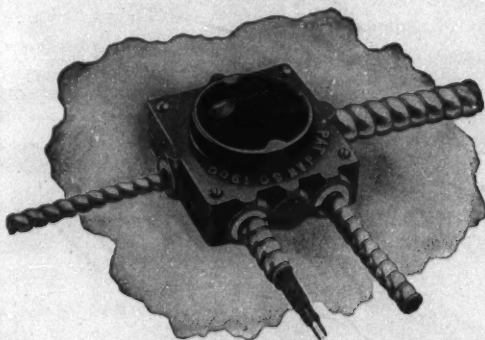
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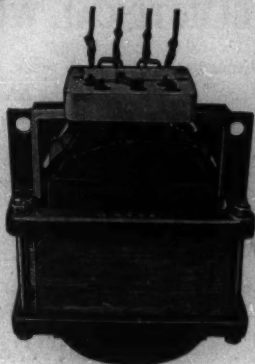
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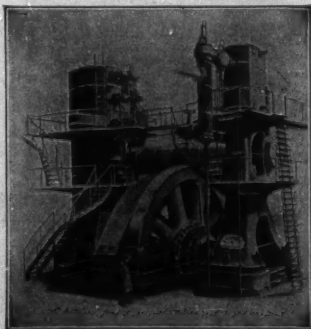


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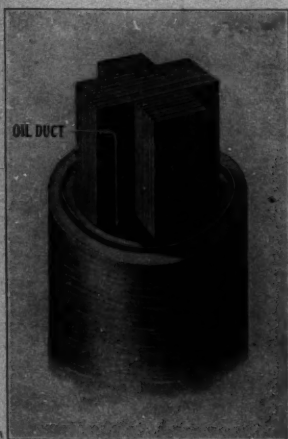
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